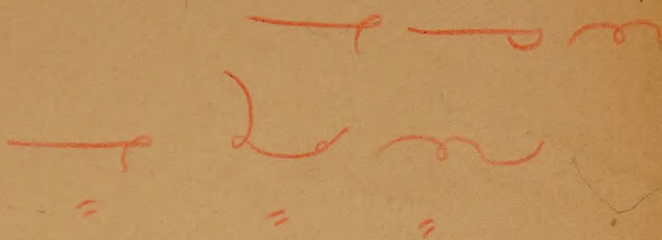


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MODERN BIOLOGY: ITS HUMAN ASPECTS

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D. C. HEATH AND COMPANY
BOSTON NEW YORK CHICAGO LONDON
ATLANTA SAN FRANCISCO DALLAS

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216

PRINTED IN U.S.A.

PREFACE

This book has been written to meet the urgent need for a text that adequately treats those phases of biology directly related to human welfare. The immense range of material available for such a text has made it necessary to select with great care those topics best suited for the purpose at hand. Often in the following pages, materials that received much attention in earlier texts are omitted to permit adequate presentation of those phases of the subject of the highest importance to the elementary student. The author has earnestly attempted to treat the topics covered in this book with sufficient thoroughness so that a clear and scientific understanding of the various subjects may be the outcome.

The present volume is the outgrowth of long contact with elementary students of biology in high school, college, and university classes. Studies made during this teaching have been very valuable in the determination of the subject matter included in this text. The author believes that the type of material treated in the following pages, and the manner in which it is presented are in line with modern views. The book is in accordance with the recommendations of the Commission on the Reorganization of Science in Secondary Schools (N. E. A. 1920), and likewise with the conclusions of other authorities upon the subject.

Long discussions of the structures of plants and animals have largely been omitted from this text. This plan was adopted in order to avoid unwarranted repetitions so often met in courses based upon both textbook and laboratory materials. *Laboratory Exercises* by Mary A. Bennett, published by D. C. Heath and Company, has been prepared expressly to supplement this text in regard to structural studies.

The author desires to thank the following people for aid given so freely during the preparation of the manuscript: Doctor W. B. McDougall, Botany Department, University of Illinois; Doctor John H. Whitten, Biology Department, Chicago Normal School; Mr. Roy Sallee, High School Principal, Oneida, Illinois; Mr. Grover Cleveland, Agriculture Department, and Miss Sophia Reed, Domestic Science Department, of the Western Illinois State Teachers College, Macomb, Illinois. Special recognition is accorded Miss Mary A. Bennett, Biology Department,

Western Illinois State Teachers College, for searching criticism during the four years while the materials included in this book have been in use in the High School connected with this institution.

The writer is indebted to Doctor Irving Garwood, Professor of English, Western Illinois State Teachers College, for painstaking criticism of the manuscript from the standpoint of English, and also to Mrs. Ross Holt, Macomb, Illinois, for valuable service rendered in perfecting the copy.

The following individuals kindly furnished photographs for use in this book—a service for which the author is very grateful: Mr. Arthur H. Estabrook, Mr. William T. Hornaday, Mr. Edward Howe Forbush, Mr. Jack Miner, and Mr. W. B. McDougall. Due credit is given in connection with the cuts. The following publishers have very kindly allowed the use of cuts and other copyright matter, or have coöperated in other ways: D. Appleton and Company, Massachusetts Audubon Society, National Association of Audubon Societies, P. Blakiston's Son and Company, Carnegie Institute of Washington, Doubleday Page and Company, Henry Holt and Company, The Macmillan Company, McGraw-Hill Book Company, Princeton University Press, Orange Judd Publishing Company, Frederick A. Stokes Company, W. B. Saunders Company, United States Department of Agriculture, John Wiley and Sons, Inc., New York Zoölogical Society, Harvard University Press, Ginn and Company, and G. P. Putnam's Sons. A number of cuts have been copied from texts written by Buel P. Colton, Charles E. Allen and Edward M. Gilbert, and William Chase Stevens, published by D. C. Heath and Company, for the use of which the author is very grateful.

Those who have aided in the preparation of the manuscript should, in no way, be held responsible for any errors or omissions that may appear in the printed volume. The author assumes responsibility for all such matters and will appreciate suggestions and criticisms by those who may use this text.

H. D. W.

CONTENTS

PART ONE — SEED PLANTS

	PAGE
CHAPTER I. FOOD IN RELATION TO PLANTS AND ANIMALS	3
CHAPTER II. THE PLANT AS A WHOLE — CORN	9
CHAPTER III. REPRODUCTION	19
Flowers	
Fruits	
Germination and seed structure	
Heredity and good seeds	
CHAPTER IV. FOODS AND THEIR USES	57
General nature of foods	
Digestion of foods — enzymes	
Respiration	
CHAPTER V. ROOTS AND THEIR RELATION TO THE SOIL ..	77
General nature of roots	
Cells	
Diffusion and osmosis	
The soil	
CHAPTER VI. STEMS AND LEAVES	119
Stems	
Leaves	
Chemical elements and plant growth	

PART TWO — SPORE PLANTS

CHAPTER VII. ALGÆ AND FUNGI	165
Green spore plants	
Non-green spore plants	
Some typical fungi	
Bread mold	
Wood-destroying fungi	
Edible mushrooms	

	PAGE
Some diseases of plants	
Wheat rust	
Oat smut	
Potato scab	
Diseases of fruits and vegetables	
Yeasts	
CHAPTER VIII. BACTERIA	203
General nature of bacteria	
Control of bacterial development	
Distribution of bacteria in nature	
CHAPTER IX. DISEASE	233
Bacteria and disease	
Some important human diseases	
Tuberculosis	
Typhoid fever	
Diphtheria	
Smallpox	
Colds	
Wounds and open sores	
Rabies	
PART THREE — NUTRITION AND HEREDITY IN MAN	
CHAPTER X. NUTRITION AND HEALTH OF THE HUMAN BODY	287
General discussion	
Digestion	
Circulation	
Respiration and excretion	
The diet	
CHAPTER XI. HEREDITY IN PLANTS AND ANIMALS	323
General discussion	
Laws of heredity	
Cases involving heredity	
Cultivated plants	
Development of the modern horse	
Heredity in human families	
"Jukes"	
The Edwards family	
The "Kallikak" family	

CONTENTS

vii
PAGE

PART FOUR — ANIMALS

CHAPTER XII. INVERTEBRATES	359
Protozoa	
Interrelations of protozoans and other organisms	
Many-celled animals	
Some important lower animals	
Earthworms	
Tapeworms	
Trichina	
Intestinal worms	
CHAPTER XIII. INSECTS	386
General discussion	
Some typical insects	
Locusts	
May-beetles	
Aphids	
Cabbage butterfly	
Parasitic insects	
Insects and disease	
CHAPTER XIV. ORGANISMS AND THEIR ENVIRONMENT	418
Interrelations of animals and plants	
Organisms in relation to the physical and chemical conditions about them	
CHAPTER XV. VERTEBRATES	436
General nature	
Economic value of vertebrates	
Geological history of vertebrates	
INDEX	473



LOUIS PASTEUR

1822-1895

The work of this man of genius laid the basis for modern antiseptic surgery and preventive medicine. Truly this brilliant but humble scientist was one of the great benefactors of the human race.

MODERN BIOLOGY:
ITS HUMAN ASPECTS

MODERN BIOLOGY

ITS HUMAN ASPECTS

PART I—SEED PLANTS

CHAPTER I

FOOD IN RELATION TO PLANTS AND ANIMALS

Foods, as we ordinarily refer to them, are substances that are taken into the plant or animal body where they are used by the organism to carry on its life processes. Those such as milk and sugar are obtained from living things, and are referred to as *organic foods*; others, such as salt and water, are known as *inorganic foods*.

The organic foods contain certain definite chemical substances, known as *nutrients*. These compounds, in a few cases, are used in pure form, as is the case with granulated sugar; but in a large proportion of our foods they occur mixed with each other and with various indigestible substances. There are three groups of organic nutrients. 1. The *carbohydrates*, which include the starches and sugars as well as some other substances not so well known, are obtained largely from our grains, vegetables, and fruits. This group is very important as a source of energy for animals and plants. 2. *Oils and fats*, which are found in both plants and animals, are, like the carbohydrates, useful as a source of energy. 3. *Proteins*, which include a large number of substances, occur abundantly in beans, peas, eggs, milk, and lean meat. This group is of especial interest in that it furnishes the materials out of which living substance is formed, and in addition is a source from which energy is obtained.

The Importance of Food. Every living thing, whether plant or animal, must have a supply of food in order to grow, move, or carry on any of the other activities connected with life. This food may be obtained from outside sources, as is the case with animals, and also with a vast number of lower plants, such as mushrooms and molds; or it may be built up out of the simpler chemical compounds within the body of the organism itself, as in the green plants. Although plants and animals seem widely separated from each other in their general nature and activities, yet the need for food and the method of its utilization in the living body are essentially the same in the two groups.

Characteristics of Living Things. One of the most characteristic properties of living substance, wherever it occurs, is its power to *build itself up* out of the non-living material or, in other words, out of food. This production of new substance is always accompanied by a *tearing down* process which continually reduces the complex living matter to much simpler compounds which are thrown out of the body as excretions. Since these two opposing processes are constantly going on in the living body, a supply of building material in the form of food must always be at hand so that the building up process may continue. Otherwise, the living substance would waste away and death would follow.

Uses of Food. The processes just referred to, as well as many other activities of plants and animals, are made possible through a continuous supply of energy in some form. So far as living things are concerned, food is the sole source of this energy. The organic substances that the body utilizes as food perform two functions, both of which are fundamental to life. 1. Food enables organisms to *renew* and *build up their tissues*. 2. Food *supplies the energy essential* for carrying on the life processes.

The Source of Food. Sugar. All energy-giving foods are produced by the green plant out of simple chemical substances, such as carbon dioxide, water, and a few others. The water is taken into the plant from the soil, while the carbon dioxide enters through the leaves from the air where it is present in small quantities. Certain other substances are used in the production of some of the foods,

but these need not be considered here. The water passes through the roots and up the stems to the green leaves where, together with the carbon dioxide, it comes into contact with the green substance found here, known as *chlorophyll*. When the sunlight, which is a form of energy, acts upon the chlorophyll, the water and carbon dioxide combine, forming a simple food substance, *sugar*. During this process, some of the energy of sunlight is absorbed and transformed into chemical energy that is held in the sugar produced. The important process just outlined is known as *photosynthesis*.

Production of Fats and Proteins. The sugar formed in photosynthesis is the basic substance from which all the other food materials are produced. Thus the plant is able to build up starches and fats from this product. The same is true in the case of proteins except that here certain other compounds besides the sugar are required. In these changes the stored energy of the sugar is not lost, and consequently foods of the types we are considering are able to supply living bodies with energy. *Photosynthesis is the fundamental process by which practically all living things are supplied with food.*

Storage of Foods in Plants. After the food has been produced in the green leaves of the plant, it is transported to various structures and stored; or, if the plant is growing, a considerable portion of it may be used directly in the production of new tissues. The various plant structures consumed by animals are, in general, rich in these stored products. Thus the *seed*, such as a kernel of corn, consists essentially of a tiny plantlet together with a supply of food, mostly starch, upon which the young seedling may feed during the process of germination. The *roots* of many plants, such as the parsnip and turnip, contain large quantities of food, as do *stems* and *leaves* of grasses, clovers, and other plants eaten by animals.

When an animal eats any part of a green plant, it is clear that the food obtained comes directly from the simple sugar that was formed in the process of photosynthesis; the same is true of the food of the non-green plants, such as yeasts or mushrooms, when

they grow upon fruit or upon the decaying parts of green plants in the soil.

Necessity of a Food Supply. It has been stated that all living things must have a constant supply of food. This is very evident in the case of animals, where there is active movement, and where it may be readily observed that starvation always results in loss of weight, and finally in death. It is not so plain that the non-green plants, such as bacteria that occur almost everywhere, the molds that grow in our pantries, and the puffballs found in the fields, also must be supplied with food at all times during their active growth. It is still less evident that the green plant that makes the food for practically all other organisms also uses at once for its own life processes a part of the product that it makes. It is not only true that all of these organisms need food, but *they all use it in essentially the same way*, namely, to provide energy and building materials for new tissues. *The green plant differs fundamentally from all other living things in being able to make its own food out of simple compounds*, a process that the animal and non-green plant in general cannot accomplish.

Method by Which Living Things Obtain Energy. The food from which energy is to be obtained is taken into the living tissues, where it comes into contact with the oxygen derived from the air. This oxygen reaches the tissues by way of the lungs or gills of the higher animals, or through other means, as is the case with many of the lower animals and with the plants. The changes that occur in the living substance are complex, but the outcome of what takes place is that both the oxygen and the food materials disappear as such, and carbon dioxide, water, and other simple substances are formed. During these changes, energy that was held in the food is released and appears as heat and energy of motion, together with other forms not so easily recognized. The simple products formed find their way back into the blood, or by some other means are finally excreted.

The Building Up Process in Green Plants. Although a green plant like corn uses some of the food that it makes in the process of photosynthesis, yet, on the whole, its activity results in

the building up, rather than in the tearing down, of organic materials. On all sides this formation of foods and other complex substances out of the simple chemical compounds is going on. Indeed, this is so common that we often fail to appreciate the full significance of the building up process. Grasses, trees, weeds, in fact, all green plants of whatever nature, during the growing season are transforming the inorganic into organic substances.

Need of Green Plant for Simple Substances. The green plant is able to use only simple chemical compounds, found in the soil and air, some of which are very limited in amount. These are transformed into the complex substances, such as wood, and other materials, of which the plant body is composed. Such organic compounds cannot be used by other green plants until they are again reduced to simple forms. The green plant, then, continually draws upon the substances which are absolutely essential for its growth, and converts these into forms that it cannot use as raw materials.

The Tearing Down Process. Were there no provision in nature whereby these organic materials are reduced to forms suitable for the use of the green plant, life as we know it would in time cease to exist. This result does not occur; for animals, non-green plants, and green plants, in so far as they use food for energy purposes, are continually tearing down the complex substances that were produced directly or indirectly by photosynthesis. Thus the supplies of some of the simple compounds are maintained in the soil and air.

Green Plants Make Possible the Existence of All Living Things. The activity of the green plant makes possible not only its own existence, but also that of all other forms of life, by providing the food substances which all must have in order to live. It is also evident that animals and non-green plants, like yeasts and bacteria, make possible the existence of the green plant by breaking down the complex substances and thus furnishing the simple compounds that are continually drawn upon in the production of the various food substances and other organic materials. Thus the two great groups of living things — the animals and non-green

plants on the one hand, and the green plants on the other — are closely bound together through their food relations.

The Importance of the Subject Matter Relating to Food and Its Uses. Much of the material concerning food and its uses is vitally connected with human welfare. In fact, a very large part of the subject matter of biology that is of great interest to the average individual is definitely related to these subjects. The production of food in some one of its modern aspects, such as vegetable or truck gardening, horticulture, general agriculture, and the raising of animals, is of fundamental interest to a large proportion of the people. Likewise, the preservation of food by canning, refrigeration, and the like, touches almost every American home.

Not only in the matters just mentioned, but also in such important considerations as human health and physical efficiency, some knowledge of food and nutrition is fundamental. A well-nourished body is a most potent factor in the prevention and cure of human diseases.

CHAPTER II

THE PLANT AS A WHOLE — CORN

The Grass Family. Of all the natural groups or families of plants, none is of greater importance to the human race than the grass family. Corn belongs to this group, as do also a large number of other plants which are of the highest importance as a source of food to man. Among these may be mentioned wheat, oats, rye, rice, and barley; also, there are the ordinary forage plants, as timothy, millet, blue grass, and a very large number of wild forms which, in the aggregate, are of great value; besides these are the sorghums, sugar cane, and various tropical plants that are very useful.

Weeds. The grass family, although in general so valuable, contains some forms that are not only useless to man, but are extremely injurious to agriculture, and are considered among our worst plant pests. The quack grass, characterized by its ability to spread rapidly and to choke out useful plants, is a notable example of undesirable grasses. Other pernicious weeds belonging to this family are the sand bur, so obnoxious in the river bottoms, the cheat, troublesome in the wheat fields, and the foxtail grasses found almost everywhere in summer.

Characteristics of Grasses. The grass plants have certain definite characteristics in common that make it easy to identify the members of this family wherever found. In general, they are small plants, although some of them, such as the bamboo, may reach a hundred feet or more in height. In this country the size varies from that of some of the wild grasses, only a few inches in height, to that of the corn, which may attain twelve feet or more.

1. **Roots of grasses.** The roots of grasses are generally of a fibrous nature, and in the small types frequently grow together in a tangle near the surface forming a more or less compact sod,

as in the case of the common blue grass of lawns. Some, however, like timothy, have bulb-like bases to the stems from which the fibrous roots extend well down into the soil. (Fig. 37.) Others, like the quack grass mentioned above, have stems known as *root-stalks* that run beneath the surface of the soil, and give off roots from the nodes. In most of the grasses, however, the fibrous roots arise from the bases of the stems and spread out through the soil, as in the case of corn. (Figs. 2 and 65.)

2. Stems of grasses. The stems are generally slender cylindrical structures divided into definite sections by enlargements known as *nodes*, which are well shown in the cornstalk. Often the nodes are solid, but the *internodes* are most frequently hollow, or filled with pith and certain other structures, as are those of corn. When very young, the internodes are often solid, but as the plant grows, the materials collect around the outside forming the hollow stem.

3. The grass leaf. The leaves of the grasses, called *blades*, generally very slender and parallel veined, clasp the stems by the basal portions, or *sheaths*, which in most cases entirely surround the stems. The blades, arranged in vertical rows on opposite sides of the stems, are said to be *two-ranked*. (Fig. 1.)

4. Grass flowers. The flowers of grasses are always inconspicuous and consist essentially of stamens and pistils surrounded by chaffy structures called *bracts*. The *stamens* are three in number, and the *pistil* is generally characterized by a two-parted, plume-like *stigma*. In some grasses, as the corn, the stamens and pistils are borne in different flowers; in others, as the oat plant, the two structures are found in the same flower. (Figs. 11 and 12.)

The Corn Plant. Its Origin. The corn plant is doubtless of American origin, having existed in the wild state in Mexico or in some other sub-tropical country, according to the best evidence available at present. The original wild plant was probably taken by primitive man in America, and cultivated in a very imperfect fashion centuries before the white man made his appearance upon this continent. The wild form from which the corn has been developed has not been identified with certainty, but it is certain that it has been modified materially during the time that it has been under

cultivation. Doubtless the wild plant was much more like the typical grasses than is the corn of today.

Corn a Hot Weather Plant. Warm weather is essential to the best development of corn. The maximum crops are produced in the corn belt, a broad strip of territory extending east and west through the north central states, and in other smaller regions locally suited to its growth. In general, these localities are relatively far north, but it is important to note that the temperature of this great interior region, far removed from the influence of the sea, is frequently very high during the long days of July and August, the months when corn is maturing. Without doubt the warm days and nights of midsummer in these states are an important factor in the growth and development of this plant. The northern limit of the region for corn growing has been greatly extended, until now some varieties of the plant are grown as far north as southern Canada. In these northern localities, however, the crop is grown chiefly for fodder as the summer is frequently too short and the nights are too cold for the maturing of the grain.

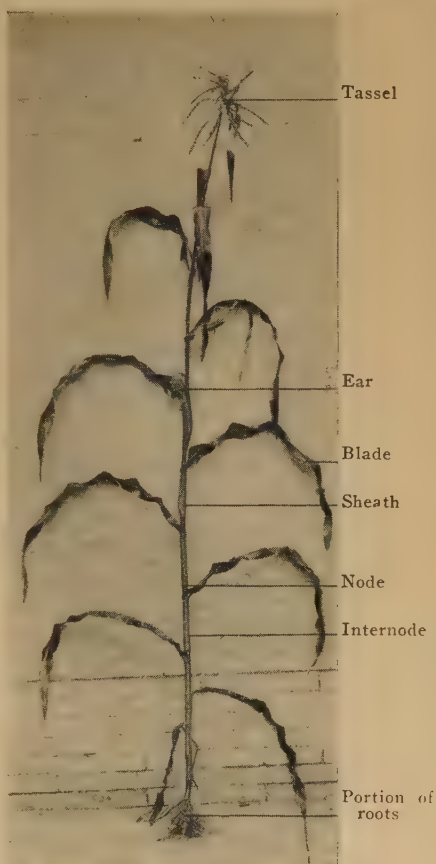


FIG. 1. — MATURE CORN PLANT
(Original photograph)

Influence of Dry, Hot Weather. Although the corn is able to stand much warm weather without injury, yet at certain periods in its development, dry, hot winds may do great damage. This is particularly true at the time when the silks are appearing and the pollen is falling. Excessive dryness and evaporation at this time interfere with the filling out of the ears. The exact way in which this injury is brought about is not entirely clear, but it seems probable that both the silks and the pollen may be injured by the atmospheric conditions, and thus pollination may be rendered impossible. (Page 24.)

Corn Roots. General Character. The roots of corn, like those of other typical grasses, are fibrous. In this plant the roots arise from the lower nodes of the stem and spread out into the soil where they divide and subdivide into very numerous tiny rootlets, almost too small to be seen with the naked eye. This interlacing mass may be said virtually to fill the soil about the corn plant. In the aggregate, the rootlets provide a very large surface that comes into close contact with an immense number of soil particles, and greatly facilitate the absorption of substances from the soil. In the earlier stages of growing plants a very large proportion of the roots are to be found in the first five or six inches of the soil. Later, as the plant develops, the roots extend deeper down until at maturity they may reach a depth of from three to four feet. In very wet soils most of the roots are near the surface. (Figs. 2 and 3.)

Kinds of Corn Roots. There are at least three kinds of roots that can readily be distinguished in the mature corn plant. 1. A considerable number of large roots arise at, or near, the base of the stalk, and pass downward at various angles into the deeper layers of the soil. These have been called *vertical roots*. 2. Another type of extreme importance to the farmer are the roots that leave the base of the plant, and after descending a short way extend almost horizontally for twenty inches or more, at a depth of only three to five inches below the surface, and finally turn down into the soil. From these, which are known as *lateral roots*, numerous fine branches arise and distribute themselves through the upper layers

of soil almost to the surface. 3. Other roots that are of considerable interest are those that arise at the nodes a short distance above the ground, and grow obliquely downward, reaching the soil a few inches from the base of the stalk. These enter the soil, branch out in a more or less extensive way, and thus become fixed in the earth. They develop about the time that the corn is beginning to produce ears, and are of value in keeping the stalk, with its ever-increasing weight, upright; hence the name, *brace roots*.

Function of Roots. Corn roots, like those of most other plants, have several important

functions. 1. The most characteristic function is the absorption of water and other substances from the soil. These are taken into the growing roots near their tips, and are carried to the stem, through which they finally reach the leaves. 2. A second function of roots, of minor importance in corn, is the ability to store food. The storage function is of great importance in such plants as the parsnip. 3. Soil roots attach the plant to the soil, and, in most cases, serve to hold it upright. This function is of great importance in relation to photosynthesis, or food making.

Corn Roots and Cultivation. In a very few weeks after planting, corn roots virtually fill every cubic inch of space in the surface soil between the rows up to within an inch or two of the top. At this time, cultivation, say to the depth of four or five inches, is certain to destroy myriads of roots that are of the highest value

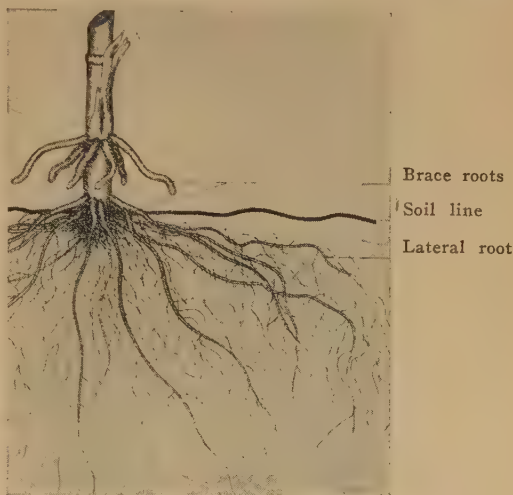


FIG. 2. — ROOT SYSTEM OF CORN
(Original)

to the plant. Thus the supply of water to the rapidly growing corn is cut off at the time it is most needed. On the other hand, shallow cultivation that stirs the ground but an inch or two deep will leave the soil in better condition by retaining the moisture, will destroy the weeds as effectively as deeper working, and do little if any injury to the roots. Hence the superiority of this practice over the earlier method of deep cultivation.



FIG. 3.—BASE OF A CORN STALK (split) SHOWING THE NATURE OF BRACE ROOTS
(Original photograph)

Stem Structure. The stem of corn, although possessing the same general character as that of other grasses, differs somewhat from the more typical forms. Most common grasses have hollow stems, but those of corn are filled with a soft, light pith through which numerous small fibers, the *fibrovascular bundles*, find their way. These structures form compact masses at the nodes from which some enter leaves which are attached at these places. In brief, these bundles extend from the ends of the roots through the stems and out into the leaves, forming the passage-ways for the transportation of materials in the plant. Bundles essentially similar to these in structure and function are found in all higher plants whatever their general nature. (Fig. 68.)

Strength of Grass Stems. The hard, resistant materials are located chiefly at or near the surface of the grass stem, forming a tube-like structure with solid portions here and there. This general arrangement of material, which is recognized as an excellent one to give strength and rigidity, is frequently used by the engineer in structural work.

Growth of Grass Stems. The stem of the corn plant grows in a curious manner also characteristic of other grasses. When the plant is young, the leaves grow much more rapidly than the stem, but about the time the tassel appears, the stem lengthens with great rapidity and the whole appearance of the plant changes. This very rapid increase in height is due to the fact that there are several distinct regions of growth in the stem. Just above each node there is tissue that retains the power of growth for a considerable period after the leaves have ceased their rapid growth. Each node lengthens independently of the others with the result noted above. The new tissue formed in these regions of growth is very tender, so that if one pulls upon a young head of timothy or similar structure in another grass, the stem will break just above a node. If corn plants or any of the small grains are blown down when green, the unequal growth that then takes place just above the nodes will cause the stems to bend upward and become practically upright again — an important factor in relation to the maturing of our grains.

Functions of Stems. The functions of the corn stem, as well as those of other stems, may be summed up as follows. 1. The water and other materials in the plant are transported and distributed by means of the stems. 2. Food is frequently stored in the stem temporarily, or, in some cases, for considerable periods of time. 3. The stem makes the erect position of the plant possible — a condition of importance in connection with photosynthesis.

Food in the Stem. In the green cornstalk there is much food, but as the plant matures most of this is finally deposited in the ear. Owing to this fact, green corn and other plants which are similar in this respect are often cut and cured or used in the form of silage as stock food.

Leaves. The leaves of corn vary considerably in number and size, and are arranged alternately on opposite sides of the stem, as is the case with all grasses. This is called the two-ranked arrangement. The leaves are attached at the nodes, and the lower portion, or *sheath*, may practically cover the internode immediately above.

(Fig. 1.) At the point of division between the sheath and the upper part of the leaf, or *blade*, there is a small scale-like appendage. This little structure may be of some use to the plant by preventing water from entering between the sheath and the stem, and by causing it to drain off and finally reach the soil at the base of the plant.

The Veining of the Leaves of Corn. In the center of the blade extending almost the entire length is a thickened strip, the *midrib*. On each side of this are the *parallel veins* similar to those found in all grasses. These veins and also the midrib contain *fibrovascular bundles*, which serve not only to carry the sap, but also to hold the green leaf surface spread out to the light. (Fig. 85.)

Wilting. In corn and other plants much water is carried to the leaves, where it evaporates. If this loss of water exceeds the amount taken in through the roots, the plant will wilt. This loss is frequently so great in hot, dry weather that injury to the plant results. Some plants have means to prevent this loss. In the corn excessive loss of water during dry, hot days causes the blades to roll up.

Function of Corn Leaves. The process of photosynthesis, or food-making, which we have pointed out as being of such importance to all plants and animals, is the all-important function of green leaves. These structures serve also as a temporary place of storage for the foods before they are transported to other parts of the plant through the fibrovascular bundles. Many animals take advantage of this and feed largely upon green leaves. Leaves are very important structures, and when they are injured the whole plant is damaged.

Flowers. The flowers of a plant are fundamentally related to seed production. In order to produce seed, two floral structures are generally necessary, the *pistil* containing the parts that may develop into the seed, and the *stamens* that produce the pollen. These structures may both be in a single flower, they may be in separate flowers, or they may be borne upon different plants. When the flowers have stamens but no pistils, they are *staminate*;

when they have pistils but no stamens, they are *pistillate*. In corn the flowers are of both types and are borne upon the same plant, the pistillate flowers occurring upon the immature ears, and the staminate upon the tassels. (Figs. 4 and 5.)



FIG. 4. — CORN FLOWERS

Left — Pistillate flowers cut from a young ear showing the attachment of the “silks” (pistils).

Right — Entire young ear with the husks removed.

Center — A portion of a tassel and a single staminate flower showing the stamens. (Original photograph)

Immature Ear. The immature ear of the corn consists essentially of a large number of pistillate flowers situated upon a central portion, or cob, and surrounded by a series of husks. The husks are similar in structure to the sheaths of ordinary leaves. The flowers are completely hidden except the tips of the pistils (“silks”), which may be seen as a more or less tangled mass at the end of the husks. One of the “silks,” together with the tiny enlarged structure to which it is attached, constitutes a single flower. The flowers, which are arranged in rows upon the cob, are surrounded by small chaffy structures called *bracts*. (Fig. 4.) These may be seen to good advantage upon the cob from a mature ear of corn.

Tassel. The tassel or staminate flower cluster of the corn bears a large number of flowers and serves to hold these well up in an

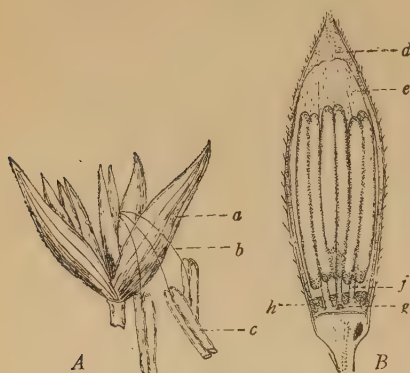


FIG. 5.—A, SPIKELET FROM THE "TASSEL" OF THE INDIAN CORN, BEARING TWO STAMINATE FLOWERS

a, one of the bracts; b, filament; c, anther.

B, LENGTHWISE SECTION THROUGH AN UNOPENED STAMINATE FLOWER

d and e, bracts; f, filament, now short, but which will become much longer when the flower opens; g, the rudimentary pistil; h, one of the two small sepal-like parts. B after Weatherwax.

exposed position. The single flower consists primarily of three stamens surrounded by bracts. In very young tassels, the stamens are entirely hidden within the bracts, but they soon burst out and are ready to release their pollen. (Fig. 5.)

Corn Pollen. The pollen, which is of a light, dusty nature, falls upon, or is carried by the wind to pistils (silks) ready to receive it. This transfer of pollen from stamen to pistil is known as *pollination*. The number of pollen grains produced by a single tassel has been estimated at from 20,000,000 to 50,000,000 and the number to each pistil, or silk, 40,000

to 50,000. This great abundance of pollen seems to be necessary in order to insure pollination, for the vast majority of grains never reach the silks. (Fig. 14.)

CHAPTER III

REPRODUCTION

FLOWERS

Importance of the Flower. The flower is an exceedingly important part of the plant, for it makes possible the production of seeds. With many plants, the seeds form not only the chief type of multiplication but also the sole means by which the species is carried over from one season to the next. This is the case with the grains. Seeds are also of great value as food supply of man and domestic animals. Of all the parts of the plant, this structure is probably the most frequently used for this purpose.

Size, Forms, and Clusters of Flowers. Flowers vary greatly in size, in form, and in arrangement upon the plant. Some are large and showy, as those of the morning-glory, while others are inconspicuous, as those of the maple and corn; some are regular in shape, as those of the apple, while others are very irregular, as the snapdragon and sweet pea; some are borne singly, as the violet, while others are in clusters of various types, as in the geranium and lilac. A brief trip through a greenhouse or in the field will impress one with the innumerable variations referred to above. (Figs. 6, 7, 8, 9, 15, and 16.)

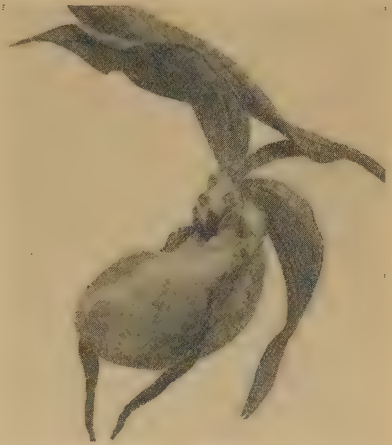


FIG. 6. — MOCCASIN FLOWER OR LADY'S SLIPPER IN WHICH THE PARTS OF THE FLOWER ARE VERY MUCH MODIFIED (Original photograph)

Parts of a Simple Flower and Their Uses. A typical flower, that is, one that contains all of the *kinds* of floral parts — such as the violet or morning-glory — is made up of several circles of structures. These parts occupy the same relative positions in the blossoms of various plants. The stem of the flower, or *peduncle*, as it is called, often has an enlarged end, the *receptacle*, to which the



June-berry.

Geranium.

Blue grass.

FIG. 7.—TYPES OF FLOWER CLUSTERS (Original photograph)

circles of parts are attached. Sometimes there are a number of green, leaf-like structures attached to the peduncle near the flower. These are known as *bracts*. (Figs. 10 and 13.)

The outer circle of parts situated upon the receptacle is called the *calyx*. This is made up of a number of more or less separate structures, called the *sepals*. These are often green, somewhat leaf-like, and serve to protect the inner portions of the flower during development in the bud. The next circle of parts situated upon the receptacle and just within the calyx is called the *corolla*. This is made up of several parts either separate or joined together, and

often highly-colored and conspicuous. These are the *petals*. In the radish, geranium, apple, and many others, the petals are entirely separate; in the petunia, morning-glory, and some common wild flowers, they are so completely joined together that it is difficult to distinguish the separate petals at all. The chief use of the corolla seems to be to make the flower conspicuous — a fact of importance in pollination. Just within the corolla is the circle of *stamens* and in the center of the flower is the *pistil*. These last named floral parts are so important that they will be treated more fully below.

Great variations frequently occur in the floral parts mentioned. Sometimes, in flowers where all the parts are present, it is difficult to identify the various structures. Any one of the circles of parts may be entirely absent, or the organs may be attached together in the most puzzling fashion. (Figs. 6 and 13.)

Stamens, Their Number and Function. The number of stamens varies much in the flowers of different plants. In flowers with five petals, the stamens are frequently of this number, as in the violet; however, they may occur in some multiple of five, as in oxalis, or they may be very numerous, as in the hollyhock. In some plants, such as the grasses, the number is three; in the lilies there are six.



FIG. 8. — FLOWER CLUSTERS OF BIRCH

1. Pistillate catkin. 2. Immature staminate catkin. 3. Mature staminate catkin. (Original photograph)

Structure of Stamen. Pollen. A stamen is made up of two well-marked parts: the enlarged tip, known as the *anther*, and the thread-like portion, called the *filament*. The anther, as it usually occurs, is an oblong or rounded structure attached loosely to the end of the filament. Within the anther is formed an abundance of yellow powder, the *pollen*, composed of myriads of microscopic grains of various shapes and referred to as *pollen grains*. These may be sticky and adhere together, as in the pumpkin, or they may be dry and powdery, as in the corn and ragweed. (Fig. 14.)



FIG. 9. — PISTILLATE
FLOWER CLUSTER OF
WILLOW (Original
photograph)

Before the pollen is released, the anther is plump and the surface unbroken; later, the surface splits or opens by some other method, and the contents escape, leaving the anther a shriveled mass, which, together with the filament, soon disappears.

Character of Filaments. The filaments in different kinds of flowers, or sometimes even in the same flower, may vary greatly in length and appearance. At times, they are very short, causing the anthers to be almost hidden by the other floral parts, as in the violet; in other cases, they are long and slender, thereby holding the anthers well out into the air, as in the box elder and in corn. In some flowers the filaments are curved in such a way as to cause the anthers to lie in protected situations, and it is not uncommon for these structures to change their positions relative to the pistil while the flower is in blossom. These variations are very interesting and full of meaning in connection with pollination. (Figs. 12 and 13.)

The Pistil, Its Parts and Function. The pistil is made up of three rather well-defined parts, but, as is the case with the other floral structures, these vary and are sometimes difficult to distinguish.

1. The structure at the free end of the pistil is known as the *stigma*. In some cases this is simply an enlarged knob roughened, or slightly sticky, as in the radish. In another flower it may be divided into two or more elongated lobes, as is the case with the geranium. Some of the grasses have stigmas that are composed of



FIG. 10. — STRUCTURE OF A SIMPLE FLOWER (Original)

plume-like branches which extend out into the air and serve to catch and hold the light, dusty pollen characteristic of these plants. The function of the stigma, whatever its structure, is to receive and hold the pollen.

2. The base of the pistil is generally enlarged into a hollow structure called the *ovary*, which contains one or more cavities. If there is but one cavity, the pistil is said to be *simple*, as in the bean; if there are two or more, it is *compound*, as in the apple.

Within the ovary are a few or many tiny, light-colored objects, known as *ovules*. These are attached to the *placenta*, a structure that contains fibrovascular bundles, and hence is able to carry food. The ovules, which appear to the eye as minute balls, develop into the seeds. The walls of the ovary which enclose the ovules give rise to the pod or to some other related structure, such as we have in the bean and morning-glory. (Figs. 10 and 20.)

3. The *style* is the portion of the pistil between the ovary and the stigma. It serves to connect the other two parts of the pistil, and, in some cases, to hold the stigma in an exposed position

where it may receive the pollen. In some cases the style is practically absent, the stigma resting directly upon the ovary.

Pollination. There are two general types of pollination.

1. The transference of the pollen from the anthers of the flowers

borne upon one plant to the stigmas in the flowers of another individual plant is known as *cross-pollination*. This must always occur when staminate flowers are produced upon one plant and pistillate upon

another, as is the case with the box elder. Some flowers that bear both stamens and pistils are also pollinated in this way because of certain adaptations which prevent the pollen from reaching or from affecting the pistil of the same flower.

2. The transference of the pollen from the anthers of a flower to the pistil of the same flower is known as *self-pollination*. This method occurs fre-

quently among our important crop plants, and it probably takes place to a greater or less extent in a large number of flowers that

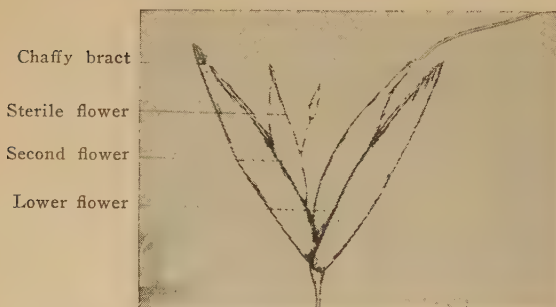


FIG. 11. — SPIKELET OF OATS PARTIALLY OPENED TO SHOW STRUCTURES (Original)

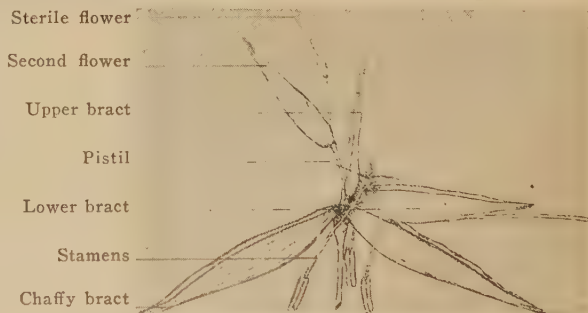


FIG. 12. — SPIKELET OF OATS FULLY OPENED SHOWING STAMENS AND PISTIL

Note that the bracts of the lower flower are separated exposing the interior structures. (Original)

have both stamens and pistils. There are many cases in which the pollen is transferred from the stamens of one flower to the pistil of another upon the same plant, as in some fruits and forest trees.



FIG. 13.—A DISSECTED VIOLET FLOWER SHOWING ITS PARTS

In the center is shown the pistil attached to a part of the peduncle or "stem." Around this in the order named are the stamens, the sepals, and the petals. (Original)

Contact-pollination. There are several ways by which pollen is transferred by the anthers coming into contact with the stigma of the same flower. Such is the case with some of the flowers of the violet, and also with several grasses which seem to be pollinated before the flowers open. In some flowers, notably those of the barberry, the stigmas may be dusted with pollen through mechanical movements of the stamens.

Wind-pollination. Many flowers are wind-pollinated; that is,

the pollen after being shed, is carried by currents of air from the anthers to the stigmas. This method is common among the trees, such as the pine and the birch, and with some of our common weeds, as the ragweed. Corn and grasses in general are adapted for this method, although, as mentioned above, contact-pollination occurs in some of these.

There are several characteristics of wind-pollinated plants that should be noted here. 1. The pollen, which is often produced in *vast quantities*, is generally *dry* and *dusty*. Wind-pollination is uncertain, for obviously the vast majority of the pollen grains are lost. Consequently, the plant must produce large quantities. The

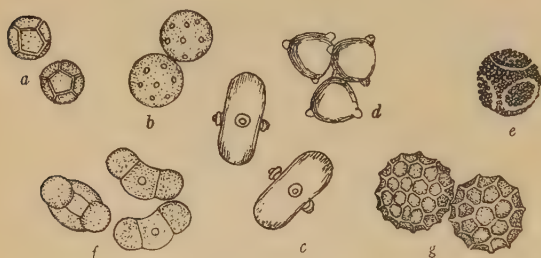


FIG. 14.—TYPES OF POLLEN GRAINS

a, pollen of one of the pinks (*Dianthus*); *b*, of the pumpkin; *c*, of *Morina persica*; *d*, of the enchanter's nightshade (*Circea alpina*); *e*, of a passion-flower (*Passiflora kermesina*); *f*, of a pine (*Pinus pumilio*); *g*, of *Cobaea scandens*. After Kerner.

light, dusty nature of this pollen enables the wind to carry it for long distances, as is the case with the pine. Cases are on record where this pollen under favorable atmospheric conditions has been carried hundreds of

miles. The pollen of the ragweed and some other common plants is very abundant and easily carried for long distances. These facts are especially significant because ragweed pollen is a common cause of hay fever, prevalent in late summer and early autumn at the time these plants are blossoming.

2. In wind-pollinated plants the *anthers* are generally in *exposed positions*, a fact which appears as an advantage in that there are fewer obstacles to interfere with the scattering of the pollen. In corn, the tassel is well up in the air away from the blades, while the anthers, which are attached by very slender filaments, hang down so that currents of air have easy access to the pollen when it is dis-

charged. The stamens of the box elder, and the staminate clusters, known as *catkins*, of many of our forest trees like the oaks, poplars, and birches, appear before the leaves are far out, and are tossed about by the slightest breeze, thus scattering the pollen far and wide.

3. The *stigmas* of wind-pollinated flowers, which are generally *exposed* to the air, are constructed in such a way as to catch and hold the pollen. In those grasses which are typically wind-polli-



FIG. 15.—FLOWERS OF BOX ELDER

1. Staminate flowers. 2. Pistillate flowers. 3. Staminate flowers after the discharge of pollen. (Original photograph)

nated, the stigmas are made up of enlarged plume-like structures that are extruded from the surrounding bracts, serving admirably to catch and hold pollen. (Fig. 12.)

4. Wind-pollinated flowers are generally *inconspicuous*, and the stamens and pistils often occur in different flowers, or even upon different plants. These characters are not invariable, although they apply in general. Some plants, such as the willow, bear flowers of

an intermediate type. These are pollinated not only by the wind but probably also by insects. (Figs. 15 and 16.)

Insect-pollination. Insects are very important agents of pollination. In fact, so essential are certain insects for the carrying of pollen in some flowers, that seeds are not produced in their absence.

Flowers that are pollinated by insects frequently have characters that are interesting and full of meaning. 1. Such flowers are often *showy*, or at least, contrast strongly with their background. This



FIG. 16.—FLOWERS OF THE BLACK OAK

1. Two-year-old acorn cups. 2. One-year-old acorn. 3. Pistillate flowers. 4. Staminate catkins. (Original photograph)

results from the large, colored corollas, or, if the corollas are white, by the strong contrast which occurs between them and the dark green of the leaves about the flowers, as in the morning-glory. Where the corollas are small, the tiny flowers are often grouped in large showy clusters, as in the goldenrod or elder. This characteristic is in strong contrast to the inconspicuous appearance of the wind-pollinated flowers, and, everything considered, it appears that the conspicuous

nature of many of these has value in guiding the insects to the flowers.

2. The *stamens* and *pistils* of insect-pollinated flowers are often more or less *hidden* within the other floral parts — a condition in marked contrast to the exposed positions of these parts in the wind-

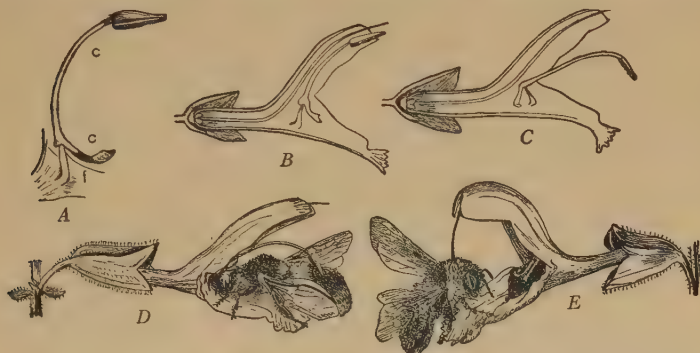


FIG. 17. — *SALVIA GLUTINOSA*, SHOWING HOW CROSS-POLLINATION IS ASSURED

A, a stamen; the short upright column (*f*) is the filament; *c, c*, the long connective, bearing the anther at its upper end. *B*, a lengthwise section of a young flower, showing the anther in its natural position. *C*, the same, the anther having been pushed down by a bee pressing on the lower part of the connective. *D*, a bee visiting a young flower; the anthers have been pushed down and are touching the bee's back. *E*, a bee visiting an older flower whose pollen has been shed; the style has now grown long and hangs down so as to touch the bee's back at the same place at which it was touched by the anthers of the younger flower. After Kerner.

pollinated flowers. In some, such as the snapdragon, the stamens and pistil are entirely enclosed by a corolla that can be entered easily only by insects such as bumblebees, which are capable of separating the two lips formed by the union of the petals. In other flowers, as those of our common fruit trees, the stamens and pistils are of moderate length and are adapted for the visitations of various insects. (Fig. 18.)

3. The *pollen* of insect-pollinated flowers differs markedly from that of the wind-pollinated in being produced in much *smaller quantities*, and in being frequently of a *sticky, adhesive* nature. The insect is a much more efficient agent for the transference of

pollen than the wind, for it goes directly from one flower to another, and thus accomplishes this transference without the great loss that has been noted in the other case. A much smaller quantity of pollen is sufficient to insure complete pollination. The adhesive character of this pollen is due to the moist, sticky covering, or to numerous microscopic projections upon the surface of the grains. This character not only prevents the blowing away of the pollen before the visit of the insect, but it also enables it to be more readily carried to the next flower. Although the amount of pollen

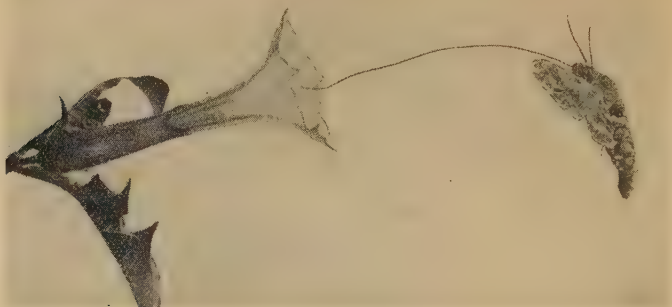


FIG. 18. — SPHINX MOTH AND FLOWER OF DATURA STRAMONIUM
Posed to show the relative lengths of the flower and of the
moth's proboscis. Reduced rather more than one-half.

produced by the insect-pollinated plant is comparatively small, yet the number of grains is vastly in excess of the ovules in the same flowers.

4. Many flowers that are habitually pollinated in this manner have *odors* that doubtless are of great value in guiding the insect to the blossom. Many insects are extremely sensitive to odors. Some, as in the case of the bees, are attracted by such flowers as the wild rose; others, as some of the flies, are found around the carrion flower. Many fragrant flowers are showy, as those of the crab-apple, but some of the most fragrant are inconspicuous, as those of the grape. It is a significant fact that many, such as the last named, seem to attract insects much more readily than some that are very showy but odorless.

5. Closely related to the odors of flowers, so far as pollination is concerned, is the production of *nectar*, the sweet substance often found in insect-pollinated flowers. This substance, which is composed largely of water in which certain sugars are dissolved, is produced and stored in a specialized structure called the *nectary*. In some flowers, as the common nasturtium, the nectar is held in a deep pocket or spur; in others, as some lilies, it is easy of access. Often highly specialized insects are found frequenting flowers where the nectar is difficult of access, as is the case with the hawk moth and the common moon flower. In this flower, the nectar is at the bottom of a very long tubular corolla and the insect mentioned has a remarkable sucking mouth part that may be extended for several inches, thus enabling it to reach the nectar. Many kinds of insects depend largely upon nectar for their food supply, and with some, as the honey bees, large quantities are stored as honey, after certain changes have taken place in it.

Some insects visit flowers to eat the pollen, as ants and certain beetles, while others carry away large amounts of it to be used later to feed the young, as is the case with the honey bee. Still others enter blossoms for sap or for shelter during the night or in rains. Nectar, however, is the most important attraction that the flower has for the insect. In entering the blossom, the insect comes into contact with the pollen, which adheres to the various parts of its body; later this pollen may be brushed off upon the stigma of another flower, thus accomplishing pollination.



FIG. 19. — *VALLISNERIA SPIRALIS*

Plant on the left bears staminate flowers which are breaking away and rising to the surface. The plant on the right bears a pistillate flower rising on a long stem to the surface. After Kerner.

Other Agents of Pollination. There are a few other methods of pollination, two of which we shall simply mention. Some flowers, as the honeysuckle, are frequented by hummingbirds which may serve to carry pollen. Some water plants that are more or less submerged have flowers so situated that pollen floating upon the surface reaches and pollinates them.

Fertilization in Plants and Animals. Fertilization consists essentially in the union of a structure known as the *male sex cell*,¹ or *sperm cell*, with another cell, generally much larger, known as the *female sex cell*, or *egg cell*. After fertilization the egg develops into the young plant or animal, as the case may be. The developing plant or animal, during the early stages of growth, is generally referred to as the *embryo*. The process of fertilization is of the highest importance to the plant, for the union of the sex cells marks the beginning of the next generation; the same, in general, is true of animals. In man some knowledge of the facts of fertilization is of far-reaching significance in the subject of human heredity.

Fertilization Practically Universal. Fertilization is a universal occurrence in all higher forms of life, whether plant or animal. Although the details of the process may vary much, it is *fundamentally the same wherever it occurs*. The corn plant is a very different form of life than a fish or mammal, but an understanding of what takes place during fertilization in the corn is sufficient to explain the essentials of what occurs in other living forms as well.

Relation of Pollination to Fertilization in Plants. Pollination in plants makes fertilization possible. The sperm cells come from the protoplasm of the pollen grains, while the egg cells are formed within the ovules. It is evident then that the transfer of pollen is merely a preliminary step which finally enables the sex cells to fuse and thus give rise to the new plant. Pollination is

¹ A cell consists essentially of a tiny mass of living substance, the *protoplasm*. Imbedded within the semi-liquid portion of the protoplasm is a denser part, the *nucleus*. In plants, the whole structure is surrounded by a covering known as the *cell wall*, composed, in general, of cellulose. The protoplasm has the power, not only of growth, that is, of building itself up out of food, but also of carrying on the life processes, such as respiration and excretion. All plant and animal tissues are made up of these microscopic units.

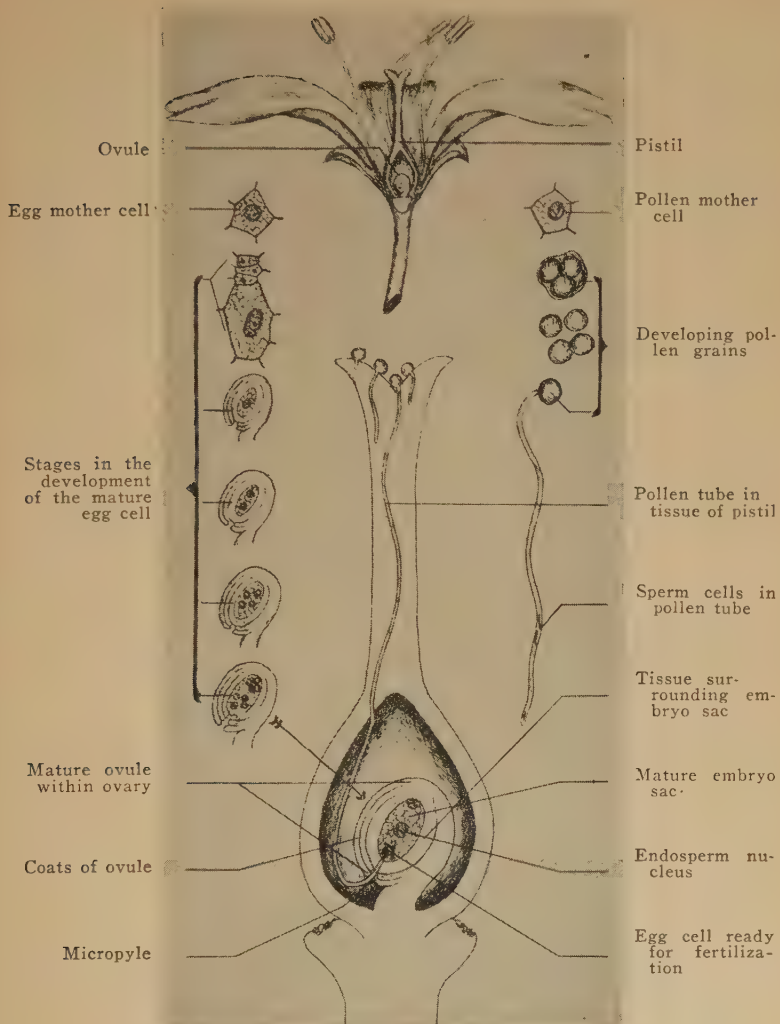


FIG. 20. — DIAGRAM OF THE DEVELOPMENT OF THE EGG AND SPERM CELLS IN HIGHER PLANTS AND THE MECHANISM OF FERTILIZATION (Original. Somewhat diagrammatic)

concerned only with seed plants, while fertilization is of very wide occurrence with all living forms.

Development of the Ovule. At a very early stage in the development of the flower of a higher plant, an ovule appears as a tiny body within the ovary. This little structure gradually becomes surrounded by one or two layers of tissue, the *integuments*, which continue to grow until only a small opening, the *micropyle*, is left. Within this structure arises a "mother" cell that upon division produces four cells, one of which enlarges rapidly and forms an organ known as the *embryo sac*. The other three cells degenerate. Within the embryo sac the prominent nucleus divides into two; these again divide, and finally eight nuclei are formed. Three of these arrange themselves at one end of the embryo sac, three at the other, and two fuse, forming a prominent central structure. One of the nuclei at the end nearest the micropyle becomes the female sex cell or *egg cell* and the one formed by the fusion near the center is the *endosperm nucleus*. When the embryo sac is in this stage of development, it is mature, or ready for the entrance of the sperms. (Fig. 20.)

Development of the Pollen Grain. The development of the pollen grain and the production of the sperms are not very different from those of the ovule and the egg cell. At an early stage in the growth of the bud, before the flower is ready to open, "mother" cells arise within the anthers. Each of these enlarges and divides and finally produces four cells that develop into pollen grains. About the time that the flower opens, these grains are said to be ripe; that is, they are ready to function in the process of fertilization.

The stigmas to which the pollen finds its way are moist and produce substances that enable the pollen grains to develop further. Certain changes occur within the grains, but the most apparent growth is the production of a microscopic tube that comes from the interior of the grain and enters the tissues of the stigma and style, thus making its way towards the ovary. When the tube reaches the cavity of the ovary, it grows toward the micropyle, enters the ovule through this opening, and thus finds its way to the embryo sac.

While this remarkable growth has been taking place, certain developments have been going on in the living substance of the pollen grain that have resulted in the production of two very small sex cells, known as *sperm cells*, which may be found near the end of the tube.

Fertilization.

These sperm cells soon leave the tube and enter the embryo sac where *one unites with the egg cell, and the other with the endosperm nucleus. This union of the sex cells is known as fertiliza-*

tion. In the animal there is but one fusion—that between the sperm and the egg cell. (Fig. 20.)

Development of Plant Embryo. After fertilization, rapid development takes place within the ovules. The endosperm nucleus divides rapidly, forming a mass of tissue, the *endosperm*, which finally consists essentially of a store of food which is used by the embryo or young plant. The young plant develops rapidly from the fertilized egg cell, and during the maturing of the seed it may use up a large part of the food stored in the endosperm. If some of the endosperm remains in the seed at maturity, it is used by the developing plant during germination.

Stored Food and Seed Development. The changes described above take place very rapidly in some cases where the food has previously been stored in some part of the plant. This is true in the soft maple and the parsnip. In other plants, such as the corn, where the plant must make the food that is to be stored in the seed, the development is much slower. The parsnip grows through the first season and stores up a large quantity of food in the fleshy root. This remains in the ground over winter, and very early the

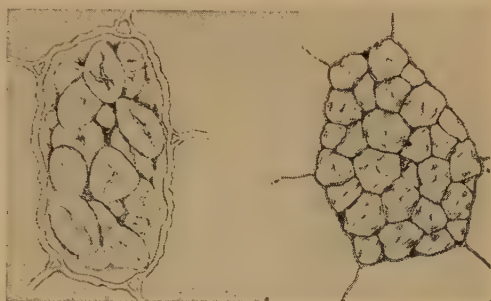


FIG. 21. — STORED STARCH

Left — Cell from a cotyledon of a bean.

Right — Cell from the endosperm of corn.
Note the starch grains crowded within the cell wall. (Original)

following spring the plant sends up a rapidly growing stem that in a surprisingly short time produces a large crop of seeds. While this is taking place the food supply of the root gradually disappears because of its storage in the seeds. The case is very different with the corn, in which there is only food enough in the kernel to supply the seedling until it is able to make a supply of its own through photosynthesis. This is a comparatively slow process at best, hence the longer time required for the maturing of the seeds of this type.

Contents of the Seed. The seed which develops as indicated above consists of two essential parts. 1. The seed always contains a young plant, or *embryo*. This may be very simple in structure, consisting essentially of two growing points, one of these giving rise in general to the parts of the plant above the ground and the other to the root system. The embryo of the corn is of this type. In many other plants, the embryo is considerably more developed and occupies practically all of the interior of the seed. The bean is a good example of this type. 2. In every mature seed there must be a food supply for the use of the embryo when it develops during germination. This food supply, which is usually abundant, is stored either in the embryo itself or in specialized tissues, most often, the *endosperm*.

In the corn kernel and in many other seeds the endosperm makes up a large part of the seed, sometimes practically surrounding the embryo. The endosperm of our grains is the chief source of flours and meals. (Figs. 21 and 28.)

The embryo during its development while the seed is maturing may absorb the endosperm formed, as in the case of the bean. In this seed, the first leaves of the embryo, or *cotyledons* as they are called, are fleshy and much enlarged, and serve chiefly as a place of storage for the food needed during germination. After this food is used they dry up and fall from the seedling. (Figs. 27 and 29.)

Development of the Animal Embryo. Just as the process of fertilization is essentially similar in plants and animals, so the development of the embryos after the union of the sex cells differs in

the two groups only in the details of the process, not in principle. The fertilized egg cell of the higher animal is supplied with food and develops rapidly into the embryo, with its various organs and tissues. This goes on until the young animal is able to obtain food on its own account.

Often the supply of food for the developing embryo is stored in a special structure in contact with the fertilized egg cell. Such is the case with the birds, many reptiles, fishes, and some other forms that reproduce by means of eggs. Embryos of these animals develop outside the body of the mother. During the incubation of the hen's egg, for example, the fertilized egg cell gives rise to the embryo, which is supplied with food from the large store present in the albumen and yolk, and, in three weeks, develops into a chick which in a short time can provide for itself.

In the group known as mammals, to which man and many of the domestic animals belong, the developing embryo is generally nourished within the body of the mother by food that is provided by the blood of this parent until birth, after which it is provided with milk until it is able to use the more complex foods of the adult.

Self- and Cross-pollination Compared. The occurrence and effects of self- and cross-pollination is a subject of much interest, and one that has some very practical aspects. In the production of pure strains of plants it is frequently necessary to use self-pollination — or at least what is very similar — pollen from a plant that is closely related to the one pollinated. This must be done in order to avoid bringing in new characters that would interfere with the purity of the variety desired. The same is essentially true with animal breeding.

Cross-pollination and Vigor of Plants. No sweeping statements can be made at present with reference to the effects of self- and cross-pollination, upon the vigor and productivity of plants in general. In some cases it seems that cross-pollination is doubtless an advantage, while on the other hand, there are many vigorous plants in which cross-pollination probably never occurs. In corn, for example, there is good evidence that cross-pollination is, in

some way, superior to self-pollination in maintaining the variety at its best. A strain that has been self-pollinated repeatedly gradually decreases to a certain point in vigor and productivity. If a plant that has been produced in this way is crossed with another pure strain that has likewise decreased in vigor, the offspring will at once be more vigorous than either of the parents. Some other species of plants are known to be affected in much the same manner as corn. In fact there is a belief among practical men, interested in the production of pure strains of plants, that long-continued self-pollination is generally injurious, and that it is necessary occasionally to resort to cross-pollination, in order to maintain the variety at its highest vigor.

On the other hand, wheat, oats, barley, and many other plants are habitually self-pollinated. If crossing ever occurs, it is the exception rather than the rule. In some plants, such as rye, self-pollination seems to be impossible because self-pollen is impotent; that is, pollen produced by the stamens of a flower is incapable of affecting fertilization in the same flower. It is probably true that self-pollen is frequently less effective than foreign pollen; and, if both are present, the foreign will function. Nevertheless, if foreign pollen is not present, self-pollen may function in many plants that have been looked upon as always being cross-pollinated.

Self-sterility in Fruits. A number of our fruits are partially, or wholly self-sterile, that is, pollen produced by a variety is ineffective upon the flowers of the same variety. It has often happened that the productivity of orchards is influenced by this. The most notable examples are found among pears, although there are varieties of apples and some of the stone fruits that react in the same way. For example, if Bartlett pears are planted exclusively in an orchard, there probably will be but little fruit set, although there may be abundance of blossoms. The same condition prevails in regard to the Kieffer. It is clear, then, that other varieties of pears should be mixed in with these in order to avoid this difficulty, as for example, Bartlett and Duchess, or Kieffer and Le Conte, or Bartlett and Kieffer. Among the apples, the Spitzenburg is self-sterile; therefore some other type, such as

the Jonathan, should be planted with the above-named variety. Some of the native plums, as well as several of the cultivated varieties, are self-sterile.

FRUITS

Definition of Fruit. A fruit, in the botanical sense, consists of a developed ovary and any plant parts that adhere to it. Thus a tomato, a kernel of wheat, or even a cocklebur, is included under this term as well as the apple, the peach, or the plum. Seeds are very generally present in fruits of whatever type. In relatively few cases these structures may not develop, as in the banana.

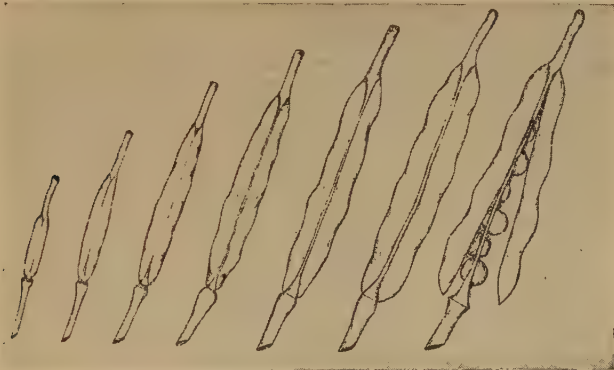


FIG. 22. — DEVELOPMENT OF THE PISTIL OF A MUSTARD FLOWER INTO THE MATURE SEED POD (Original)

Development of Fruits. Immediately after fertilization very definite changes occur in the flower. In those containing all the floral parts, the petals and stamens generally dry up and soon disappear. The calyx may persist in a more or less modified form, and remain as a part of the fruit, or it also may fall. The stigma and style sometimes are lost, but often they become a part of the fruit. The most marked developments, however, take place in the ovary and its contents. (Fig. 22.) Not infrequently remarkable structures originate from the receptacle or calyx.

Influence of the Sperm Cells upon the Development of

Fruits. The entrance of the sperm cells not only marks the beginning of the development of the egg and endosperm in higher plants, but at the same time it stimulates growth in the ovary wall, receptacle, and other structures. These last-named parts often enlarge rapidly and form the chief bulk of many of our fruits, such as the strawberry, the pumpkin, and the apple.

Seedless Fruits. Most of our plants form their fruits as described above with the seeds present in greater or smaller numbers. In some, however, the seeds fail to develop, and thus we have the seedless types of orange, gooseberry, and persimmon. Pollination seems to be essential to start the development in some of these cases. More remarkable than this is the fact that there are some cases where seeds are produced without typical pollination.

Some Types of Fruits. **Bean.** The fruit of the bean consists of the pod together with the enclosed seeds. The pod develops from the walls of the ovary of the bean flower, and the seeds from the ovules. (See discussion of the flower, page 23.) When ripening, the pod generally dries and bursts open, releasing the seeds, which in wild plants of this type fall to the ground and later germinate. **Apple.** The apple, which is a typical fruit in the popular sense of the term, consists largely of a juicy pulp that surrounds the central core in which the seeds are borne. This central portion develops from the ovary and its contents. The remains of the calyx are frequently to be seen at the "blossom end" of the apple. The pulp is looked upon as developing from the receptacle of the flower. **Cocklebur.** The cocklebur is a very different type of fruit. The numerous hook-like appendages on the outside serve as a means for dispersal of the burs. Within the tough outer coat are two seeds. One of these is said to grow during the first year and the other at a later date. This explains to a certain degree why this weed is so hard to kill out. **Corn.** The ear of corn may be looked upon as a cluster of fruits. The single kernel consists of a seed developed from an ovule about which there is a firm coat made up of the original seed coats joined to the ovary walls. Numerous other common types of fruits may be seen in any locality where wild plants are abundant.

Necessity for Seed Dispersal. Many plants produce such large numbers of seeds that dissemination or scattering is necessary in order for them to have room to develop. A single plant of the common pigweed, for example, may produce a million seeds. If all of these should fall to the ground and germinate in the space covered by the parent plant, they would be so crowded that none



Cocklebur

Beggar-ticks

Burdock

FIG. 23. — SOME FRUITS SCATTERED BY MEANS OF HOOKS AND BARBS
(Original photograph)

of them could develop. This crowding out actually occurs with many weeds and other plants along the roadsides and in our gardens and fields. Often along sidewalks, where maple or elm seeds have fallen, a thousand times as many germinate as can possibly develop. With most plants, the means for the dispersal of the seeds are in no way adequate to prevent this crowding. With some others, such as the thistle and wild lettuce, the seeds are much more widely scattered.

Agents Active in Seed Dispersal. There are several agents which are active in the dissemination of seeds. 1. *Wind*. The most effective agent, at least with a large number of plants, is the wind. Fruits or seeds that are carried in this way frequently have very interesting structures that aid in dissemination. Thistles, dandelions,



Milkweed

Dandelion

FIG. 24. — SEEDS SCATTERED BY MEANS OF THE WIND (Original photograph)

and numerous others develop downy structures referred to as *pappus* which act in the manner of parachutes, and enable the seeds or fruits to fly very long distances. Plants disseminated in this way frequently invade new areas, and cause much trouble. Other striking structures of some fruits scattered by the wind, are *wings*, such as those upon the seeds of the maple and elm. These are membranous outgrowths that materially increase the surface of the fruits, and aid in their buoyancy. These structures are less effective than the pappus. Winged seeds are seldom carried more than a few rods. (Figs. 24 and 25.)

Another structure, or set of structures, that is very effective as an aid in the dispersal by the wind, is represented in the so-called *tumbleweeds*. These plants are not closely related, but are alike in that the seed-holding structures — in a number of cases practically the whole plant — have developed into a more or less spherical form. During the winter tumbleweeds break off and blow over



FIG. 25. — WINGED FRUITS WHICH ARE CARRIED SHORT DISTANCES BY THE WIND (Original photograph)

the ground for long distances, scattering the numerous seeds as they roll. Among these may be mentioned old witch grass, Russian thistle, and one of our common pigweeds. These types are often seen in level regions in the winter lodged in great windrows, almost covering the fences.

2. *Water*. Water is not so important as wind in the dispersal of fruits and seeds, though in some cases it is very effective. The fruits of some water plants are carried long distances, but more important to us are certain cases where troublesome weeds are widely scattered by overflowing streams, and to a less extent by surface

water following very heavy rains. This is frequently the case in bottom lands where cockleburs and others are carried considerable distances by the overflow and are left when the water recedes.

3. *Animals.* The dispersal by animals often occurs in the case of *bur-like fruits*, such as the burdock, cockleburs, and certain others that have barbed or hooked appendages. With these, the



FIG. 26.—CAPSULES OF EVENING PRIMROSE

Animals jar these fruits which are borne upon rigid stems and thus the seeds are thrown for short distances. (Original photograph)

fruits become entangled with the fur of the animal, and thus they may be carried for a long distance before being dropped. (Fig. 23.) *Fleshy fruits*, such as wild cherries and many others, are often carried by birds. Robins, blackbirds, thrashers, and others swallow the fruits containing the seeds, and the latter, uninjured by the passage through the digestive tract, are dropped far and wide. The

occurrence of such plants along fence rows and telegraph lines doubtless is due largely to this sort of dissemination. Squirrels and various related animals often carry *nuts* and *acorns* far from the trees that produce them, and thus play a considerable part in seed dissemination.

4. *Mechanical Dispersal.* In some cases, seeds are scattered by being thrown from the pod or capsule, but this method of dispersal is relatively unimportant. In the garden balsam, the fruit suddenly breaks open with enough force to scatter the seeds for several feet from the plant. Another method somewhat related to this is illustrated in the butter-print, a common weed of the corn fields. This plant is so rigid when mature that when the wind or an animal jars it, the seeds are thrown out of the capsule and may go several feet.

GERMINATION AND SEED STRUCTURE

Definition of Germination. As the seed ripens the embryo ceases to develop and passes into a resting stage in which it may remain indefinitely. Under suitable conditions active growth may again take place. *This renewal of the development of the embryo,*



FIG. 27. — STRUCTURE OF BEAN SEED

Left — External view. *Center* — Part of the coat removed to show the position of the radicle in relation to the micropyle. *Right* — A portion of one cotyledon removed exposing the plumule. (Original)

which results in the production of the young plant called the seedling, is known as germination.

Embryo of the Bean. The embryo as it occurs in the bean,

consists essentially of two growing points, the *radicle* and the *plumule*, connected by a central axis, which in the main constitutes the *hypocotyl*. The *two cotyledons*, or seed leaves as they are sometimes called, also form part of the embryo. These are attached to the central axis and serve in this seed as storage tissues. When the bean is maturing, the food supply furnished by the parent plant is absorbed by the developing embryo and stored in the cotyledons. During germination this food is changed to soluble forms and carried to the growing parts which develop into the structures of the seedling. (Fig. 27.)

Embryo of the Corn Kernel. The embryo of the corn kernel, like that of the bean, consists of two growing points, the radicle and the plumule, together with a fleshy structure — the *single cotyledon*. Unlike the bean, however, this last named part is not primarily a storage organ, but serves as a means for the absorption of the food



FIG. 28.—STRUCTURE OF THE CORN KERNEL (Somewhat diagrammatic)

A given structure is represented by the same design in each section. (Original)

which supplies the developing parts during the growth of the seedling. In the corn, the food store is largely in the endosperm which is outside the embryo. In the development of the corn embryo, growth ceases before all of the food supplied by the parent is taken into the young plant. During germination the stored food is used by the seedling in the same way as in the bean, that is, for the growth processes. (Fig. 28.)

The corn is called a *monocotyledon* on account of having but one cotyledon in the seed. The bean is referred to as a *dicotyledon* due

to the presence of two cotyledons. Most of our common plants belong to one or the other of these two types.

Development of the Bean Seedling. During germination the cotyledons of some plants, like the bean, appear above the surface, while in other plants, like the pea, these structures remain in the ground. In the bean the first root develops rapidly from the radicle



FIG. 29. — DEVELOPMENT OF THE BEAN SEEDLING (Original photograph)

and soon sends out many branches that serve to fix this portion of the seedling firmly in the ground. A rapid elongation of the hypocotyl now occurs, and, as the lower end of this structure is held fast by the branch roots mentioned above, an arch is formed that grows upward, breaks the soil, and finally draws the heavy cotyledons out of the ground. The arch thus formed rapidly straightens out, and the cotyledons separate, exposing the plumule, which rapidly develops into stem and leaves. The cotyledons are soon freed of their food and in a few days dry up and fall off. (Fig. 29.)

In the *pea* which is closely related to the bean, the cotyledons remain in the ground during germination. The plumule grows rapidly, and with the tender tip turned down, it comes to the surface. When above the ground, the bend soon straightens up and the leaves develop at once. The cotyledons in this case decay soon after their food supply is exhausted.

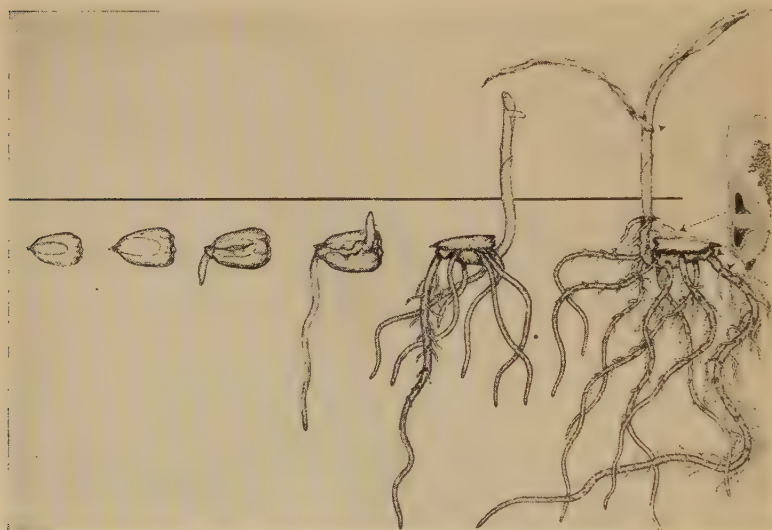


FIG. 30.—DEVELOPMENT OF A CORN SEEDLING

Arrows at the right indicate from what seed structure each part of the seedling develops. (Original)

In some other plants, the cotyledons serve for food storage in the seed but later develop into green leaves that function for some time. This is true with melons, pumpkins, and numerous wild plants.

Development of the Corn Seedling. In the corn plant, which is a typical example of the monocotyledons, the growing points of the embryo develop much as in the bean,—the radicle giving rise to the root and the plumule to the shoot. The appearance of the seedling as it penetrates the soil, however, is quite different from that

of the bean or pea. The shoot of the corn as it comes to the surface is a pointed structure made up of an external, hollow sheath within which are the developing tissues that produce the blades. The sheath serves to penetrate the soil and at the same time to protect the tender parts within. Soon after reaching the surface, this covering splits and the blades appear. The root development does not differ very much from that of the bean. When the food of the endosperm is exhausted, the kernel softens and finally decays. (Fig. 30.)

Rate of Growth of Seedlings. Seedlings of the plants we are discussing develop rapidly if conditions are favorable. They can do this because of the abundant supply of stored food within the seed. This remarkable growth is shown especially well in the root system grown in sand or loose soil. When the stored food is used up the plant has to depend upon its own ability to manufacture a supply; consequently the rate of growth is often less rapid. As the leaf surface increases, the amount of food becomes greater and growth is thereby accelerated.

Water and Seed Development. The presence of water in considerable amounts is essen-

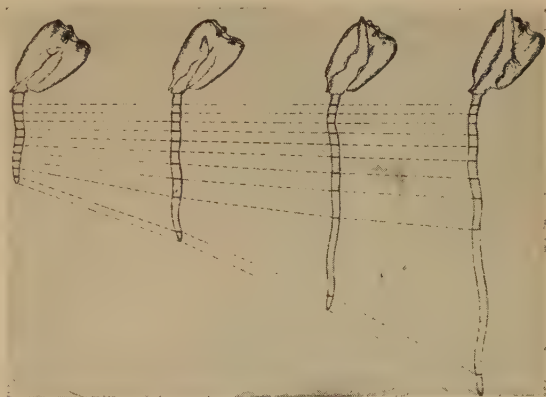


FIG. 31.—ROOT GROWTH IN A CORN SEEDLING

Ink marks were made upon the sprout and successive drawings were constructed at intervals of four hours. (Original)

tial to the seed in order that growth may take place. Consequently during the development of the embryo and the storing of the food in the cotyledons of the bean an abundance of water is present in these organs. At the time of ripening, when the seed is entering the

resting stage, a very large proportion of this water is lost, leaving the entire structure relatively dry. During this drying period the various parts of the seed gradually decrease in bulk and become much firmer. Before growth can again take place in the seed, a large amount of water must be taken in. Hence the initial stage preceding active germination in all seeds consists in the entrance of water into the various seed structures, which are thus brought into a condition where growth is possible.

Temperature and Seed Development. Another factor of great importance in germination is temperature. Seeds that are

sufficiently moist and yet are kept too warm do not grow, and the same is true of those that are too cold. The temperature at which the growth of the embryo proceeds most rapidly varies much in different seeds. With corn, melons, and other plants, a degree of heat corresponding to that of our warm June days, or even higher, gives good results; while with certain others, such as oats and red clover, quite rapid development occurs in the much colder weather of early spring. The temperature giving the maximum growth differs so widely in plants of various species that a statement applying to all cannot be made.

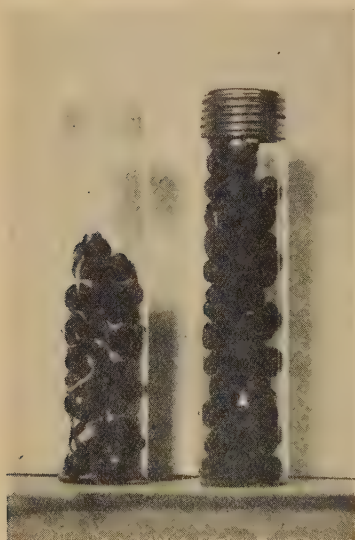


FIG 32.—EFFECT OF AIR UPON GERMINATING PEAS

Left — Soaked peas in contact with air. *Right* — Soaked peas with but a small quantity of air present. (Original photograph)

Effect of Changing Temperatures upon Growth. With all living things there is some temperature at which growth takes

place very slowly. This may be down near the freezing point. As the degree of heat increases, the rate of growth advances steadily until a point is reached where the most rapid development for the

given plant or animal takes place. If the temperature is raised higher and higher above this point, the rate of growth slows down and ceases entirely; finally death ensues.

Air and Seed Development. A supply of air is an essential factor for the growth of seedlings. Moist peas shut away from the air will not germinate. The fundamental processes underlying growth in the higher plants require a supply of oxygen and do not take place, normally, in its absence. A soil so full of water as to exclude the air with its supply of oxygen is not suitable for the germination of the seeds and the growth of most of our common plants. (Fig. 32.)

Storing of Seeds. The water content is the most important factor concerned with the life of stored seeds. If seeds are well dried out when stored, and the air about them contains but little moisture, other conditions, such as heat and cold, have but little or no effect upon them. The extreme longevity of some seeds, such as certain legumes, and some weeds, depends largely upon the fact that their coats are practically impermeable to water until changes occur in them when buried in the soil. If the air in contact with stored seeds has a high relative humidity, the seeds are likely to absorb more or less water and thus be much weakened or killed in a comparatively short time.

HEREDITY AND GOOD SEEDS

Importance of Good Seeds. There is no factor in the growth of the plant that is of more far-reaching importance, save possibly the fertility of the soil itself, than is the character of the seeds. Not only the vigor of the seedling but also the qualities of the mature plant depend very largely upon the seeds. If the seeds are poor no amount of care in the cultivation of the plant or in the fertility of the soil can entirely make up for the lack. A little extra care given to the selection of seeds generally yields big returns at harvest time.

The Vigor of the Seedling. Food Supply. The embryo in the seed is absolutely dependent upon the food stored within the

seed until it develops far enough to make food on its own account. Consequently an abundant food supply is essential for the production of vigorous seedlings. The corn plant which develops from a kernel deprived of most of its endosperm, is very small and weak as compared to the normal seedlings, and certainly much less able to provide food for itself. (Fig. 33.)



FIG. 33.—THE EFFECT OF REMOVING THE ENDOSPERM UPON THE DEVELOPMENT OF CORN SEEDLINGS

Left — Endosperm intact. *Right* — Endosperm partially removed. (Original photograph)

Injury to the Embryo. The seeds may be well supplied with food and still lack vigor. If the embryo has been injured while maturing or during storage so that it cannot develop properly, or if the external conditions are not suitable for growth, the seedling is likely to suffer accordingly. Every person experienced in gardening has observed the fact that when seeds germinate rapidly and grow vigorously from the first, a much better crop is generally produced than is the case when similar seeds have been in the ground a much longer time but have been held back in some way.

Hereditary Nature of the Seed. The most vigorous growth may take place in the seedling, and yet the plant may turn out to be worthless. Hereditary characters, or in other words, those characters that are passed down from the parents through the sex cells to the offspring, often largely determine the value of the mature plant. Characters such as sterility, form of ear, and productivity in corn, and the qualities of radishes that make them suitable for food are of this type. In fact, inheritable characters involve every part of the plant and largely determine what the plant is to be. If an ear of corn, for example, is from a type in which many sterile stalks appear, a character all too common in the ordinary field, the seed from this is likely to be worthless, and although it may grow well, it is very unwise to plant it. Since the importance of the hereditary nature of seeds in general can scarcely be overestimated, great care should be exercised to gain a knowledge of these facts.

Reason for Selection of Seed in the Field. Since the inheritable qualities represented in the seeds are frequently visible in the parents, a careful study of these plants may give valuable information concerning what may be expected to appear in the next generation. If the flowers are habitually self-pollinated, the single parent will indicate much as to the probable nature of the offspring. If cross-pollination is the rule, the problem is much more complicated, for it is often difficult or impossible to determine the nature of the pollen-producing parent. Notwithstanding this, much may be learned by a study of the nearby plants, for it is from these that the pollen is most likely to come; and if certain undesirable characters appear frequently here, there is a fair likelihood that they may affect the seed of the other plant.

The Selection of Seed Corn. If the ears in the crib are chosen because of their size and general appearances, little or nothing is known of the nature of the parent plants. An ear might develop upon a hill of corn consisting of but a single plant and under the most advantageous conditions for growth, while another ear although smaller might mature under much less favorable circumstances and consequently be more valuable for seed. Such matters

as this, together with the size of the plant, the height of the ear from the ground, the character of the husk, and the like, can only be known by field observation of the plant. Moreover, the character of the nearby plants that probably produced the pollen may be observed in the same manner, and thus some knowledge of both parents is made possible. Virtually the same conditions exist in many plants that are reproduced by seed, and in such cases field observations are valuable. The study of the parent plant in the field or garden is the most essential step in the selection of seeds of high quality.

Seeds That Come True to Type. One of the greatest difficulties in raising many of the ordinary garden or field crops is procuring seeds that will produce plants similar to the original parents, year after year, or in other words, seeds that will *come true to type*. For example, a package of garden seeds of high quality may produce uniform and excellent vegetables the first year. If seeds are saved from these plants without any special care and used the following season the ensuing crop is likely to be much less uniform and less satisfactory. This course, continued for a few years, will generally result in producing vegetables that have almost entirely lost their original excellent qualities. In other words the seeds have "run out."

Cause of Deterioration in Seeds. This deterioration in the quality of seeds may be due to a considerable extent to foreign pollen that brings in the undesirable qualities, or it may arise from the less desirable characters already in the variety that appear when care has not been used in selecting the best type for the production of seeds. Plants that are cross-pollinated, as a rule, fail more rapidly to come true to type than those that are self-pollinated.

How Plants are Kept True to Type. Varieties of plants are kept true to type through the most watchful and painstaking care on the part of expert seed growers. An example will best serve to show how this is done. A man who is desirous of furnishing high class seeds of a certain dwarf lima bean will plant the best seeds of this variety obtainable in suitable fields. During the growth of the beans, men who know the type thoroughly are employed to go

through the fields, sometimes on hands and knees, to look over every plant in search of those that vary from the type. Such variations relate to the size and habits of the plant, time of maturity, vigor, and the like. Plants that vary from the typical form of the variety are removed and destroyed, leaving until maturity only those of the most uniform and promising nature. A large portion of the seeds thus produced are placed upon the market; some however are kept that the same process may be carried out the following season.

Thus, year after year the seeds of a variety are kept true to type through the constant selection of the best plants that appear. Many other seeds that are of high quality are produced in much the same way as the beans. As this painstaking process is time-consuming and expensive, really high-class seeds sell at advanced prices.

Improved Varieties. If the selection just mentioned is carried on very carefully and only plants of marked superiority are kept, the result may be an improved variety very much better in some ways than the original. The improved strains of older and well-established varieties appearing so constantly in recent seed catalogs have generally been produced in this way. On the other hand, if rigid selection is not carried on in the production of seeds, the type will soon become impure, because of wider and wider variations that appear in the course of a few generations. Constant watchfulness on the part of the seed grower is the price of a high-class product.

The Reason Seeds Run Out in the Ordinary Garden. Often people who raise vegetables for table use save their own seeds. Although the seeds are superior in the beginning, the quality is likely to become poorer as the seasons pass. The best specimens in the row, for example, are often used for the table and those of poorer quality left. If these latter are saved for seed, a very inferior quality is bound to result. It is true that more careful people may mark the best plants in their bed, and save these for seed. Even this, however, does not overcome the danger of producing poor seeds, for often cross-pollination must be considered.

It is difficult for the average person to save seeds from the garden and keep a variety true to type year after year. Much

better results are reached by buying first-class seeds from a reliable seed merchant. Cheap seeds are generally poor from the standpoint of vitality or from that of quality. The initial cost of a superior product is greater, but in the end, these seeds are by far the cheaper.

CHAPTER IV

FOODS AND THEIR USES

GENERAL NATURE OF FOODS

Common Meaning of Foods. Foods, as the term is generally used in the home, are mixtures of organic and other substances which may be used by the lower animals or man for the nourishment of the body. Besides the varying amounts of organic nutrients, most of our foods contain salts and water, as well as ash and other materials. For example, milk, which is a typical food in this broad sense of the word, contains carbohydrates in the form of sugar, fats in the form of butter fat, and proteins in the form of casein. Water and salts, as well as small amounts of other materials, are also present. All of these substances vary in amount in samples of milk from different sources. Foods, then, as we think of them in our homes, are *mixtures* of a rather wide range of substances.

Definite Nature of Nutrients. The *variable character* of foods, as defined above, is in marked contrast to the *definite composition* of the various types of the nutrients. The *nutrients are chemical compounds and consequently do not vary in their composition*. For example, glucose, which is one of the carbohydrates, is always the same substance no matter from what source it is derived.

The fact that our common foods, such as bread, milk, and fruits, are mixtures of various substances and consequently vary much in composition, renders it necessary in scientific discussions to consider the amounts and kinds of nutrients present in these materials. In fact, food, as it is used in scientific work, very generally refers to the nutrients present rather than to the substance as a whole. For example, such expressions as, "food storage," "food supply of seeds," "sources of food," and the like, really have reference to the definite chemical nutrients involved.

Food Stored in Seeds. Seeds are among the most important organs of the plant in which foods are stored. This is the reason these structures are used so constantly for the nourishment of many types of the lower animals as well as of man. The seeds of plants afford convenient materials for the study of the nature of the various nutrients, as well as the changes that occur in these substances within the plant or animal body. Carbohydrates are very common storage products especially in our grains, but fats and proteins are also abundant in many seeds.

Carbohydrates. *Starches* and *sugars* are by far the most important substances included under this head. Others that may be mentioned are: *cellulose*, found abundantly in plant tissues; *dextrines*, which are present in toast and many toasted breakfast foods; and *glycogen*, the storage form of carbohydrate in the liver and muscles of animals.

Composition. Carbohydrates are composed of three chemical elements: carbon, hydrogen, and oxygen. The hydrogen and oxygen are generally in the proportion in which they are found in water, — that is, two atoms of hydrogen to one of oxygen. Glucose, for example, has the chemical formula: $C_6H_{12}O_6$, and cane sugar, $C_{12}H_{22}O_{11}$.

The Occurrence of Carbohydrates. These nutrients are by far the most abundant found in plants. They occur as storage products in large quantities in all of the grains and in a large number of other plants. Such structures as tubers, roots, stems, and green leaves, often are rich in these substances. Cellulose, one of the forms of carbohydrate, makes up a large part of the supporting tissues of green plants, such as ordinary cell walls and certain fibers. It also may become somewhat modified and form wood and cork. This extreme abundance of carbohydrates is to be expected, for as was pointed out in Chapter I, the final product of photosynthesis in green plants is a simple sugar, glucose, and from this as a basic substance the other forms found in this group of nutrients are readily produced.

The Relation of the Various Forms of Carbohydrates to Each Other. The types of carbohydrates are very closely related.

They are composed of the same chemical elements, which occur in much the same proportion by weight in each of them. Because of these similarities, it is easily seen why these related forms may be changed readily from one to another in the plant or animal. The plant transforms sugar into starch or starch into sugar apparently with the greatest of ease; or it may change one sort of sugar into another, more suitable for storage or for the use of the growing tissues, as the case may be. Changes very similar to these take place during digestion in man and the lower animals.

If one compares the chemical formulæ of two typical carbohydrates, for example, glucose — $C_6H_{12}O_6$, and starch — $C_nH_{10}O_5$,¹ one will see at once that the apparent difference between the two substances is that there are two more hydrogen atoms and one more oxygen atom in the glucose than in the starch. In other words, the difference between the two is apparently a molecule of water. It appears from this that the change from one of these substances to the other may be brought about by the addition or removal of water from the molecule. These changes are not brought about simply by mixing starch and water in a test tube or by removing some water from glucose by drying or other physical means, but by chemical changes in which the chemical elements in water become a part of the molecule or the reverse.

The starch in the endosperm of germinating corn is changed into glucose through the activity of substances known as *enzymes*. And again, the starch from the kernel may be transformed in the syrup factory, with the aid of dilute hydrochloric acid and heat, into glucose and related substances.

Sugars. Their Occurrence. Sugars are the simplest forms of carbohydrates that are present in plants in any considerable amounts. They occur dissolved in the sap either in the cells or in the conducting tissues. In fact, carbohydrates are practically always transported from one place to another in plants and animals in this form. As has been pointed out before, a simple sugar is the basic substance out of which all of the other nutrients are built up, hence its common occurrence in the living tissues.

¹ For simplicity we are using the empirical formula for starch.

Kinds of Sugar. Several kinds of sugar are of common occurrence in plants and animals; namely, glucose, cane sugar, milk sugar, and malt sugar.

Glucose ($C_6H_{12}O_6$). This is the simplest and by far the most common form of sugar found in plants. All other sugars, and in fact, all other forms of carbohydrates are reduced to this or very closely related forms before they are used in the tissues of plants and animals. Digestion of carbohydrates wherever it occurs, in the kernel of corn or in the digestive tract of man, finally results in the production of the simple sugars. Consequently, these are found very widely distributed in most forms of life. Corn syrup owes its sweet taste to this substance.

Cane and Other Sugars. *Cane Sugar* ($C_{12}H_{22}O_{11}$), which is the chief commercial type, is chemically more complex than glucose. It is obtained from two sources, sugar cane and sugar beets. *Milk sugar*, which is very similar to cane sugar, comprises the carbohydrate supply in milk. It is not found in plants. *Malt sugar*, another form very similar to cane sugar, occurs frequently as an intermediate product when starch is being changed into the simple sugars.

Sugars as Food. As has been indicated above, sugars are of great importance in the nutrition of the plant, as well as of many animals, including man. Many insects, such as honey bees, depend largely upon the sugary secretions of plants. In green fodder, sugar forms an important constituent, and is of common occurrence in our fruits and vegetables.

Civilized man looks upon sugar as an absolutely essential food substance. He does not depend upon the amounts he would get simply by eating the foods referred to above, but has built up great industries to meet the demand for this substance in pure form. The restrictions placed by the government to conserve the supply during the last years of the Great War, indicate the tremendous value of sugar to civilized man.

Starches. Occurrence. Starch is the most abundant storage form, not only of carbohydrates, but of any of the nutrients found in plants. It occurs as small grains of various sizes and shapes within the cells of plants. The living tissues in almost any part of

the plant may serve as a place of storage. Thus we find starch in stems, roots, leaves, and fruits of many species of plants. Some of these parts are used for temporary storage, as is often the case with the leaves. During the day carbohydrates seem to be formed more rapidly than they are transported, hence they accumulate in the leaves. At night they are likely to disappear from these parts and be stored in more permanent locations.

Storage Organs. A great many plants have specialized organs that serve for the storage of starch and other foods. These structures are often so changed in appearance that they lose practically all resemblance to the part from which they have originated. In the sweet potato the storage organ is a root, in the Irish potato an underground stem, a tuber, and in the cotyledons of the bean, the leaves.

Characteristics of Starch. Starch is very much more complex chemically than any of the sugars. During digestion the large molecules of this carbohydrate become split up into the smaller and simpler ones characteristic of the sugars. Starch is not soluble in cold water; in fact, the grains are scarcely affected at all in this way, but simply float around, forming a milky mixture that readily settles and becomes clear. When starch is dried out as is ordinarily the case in well-matured seeds, it becomes a very concentrated food substance admirably adapted for storage.

Heat upon Starch. Hot water has a marked effect upon starch in that it causes the grains to swell greatly and form "starch paste," an opalescent mixture that does not settle readily. It is significant that the process of cooking changes the hard, compact grains of raw starch in the way just indicated so that the digestive fluids of man may attack them to much better advantage. The effect of heat upon starch may be easily observed under the microscope through a comparison of the grains from a raw potato with those of a well-boiled specimen.

Starch as Food. It is difficult to overestimate the importance of starch as food. It is found almost universally distributed in green plants; consequently it becomes the food of all animals that feed upon these. Man not only depends upon starch from the grains,

potatoes, and numberless plant structures for his own food supply, but he also uses it to feed animals, such as cattle and hogs, which in turn furnish him with meat and milk.

Fats and Their Occurrence. Fats is the name applied to a large group of substances, like olive oil and tallow, that are closely related, chemically. They also have definite physical similarities, such as being soluble in ether and benzene and insoluble in water. The fats are not only very common as stored food materials in animals, but they also occur in more or less abundance in a large variety of plant structures, especially in seeds. In some of these the stored food is very rich in fat, as is the case with nuts and the castor bean. Even in the corn kernel, where carbohydrates predominate and the stored food seems anything but oily, fat occurs in rather large quantities.

The Chemical Composition of Fats and the Forms in Which They Occur. The chemical elements of which fats are composed are the same as those found in carbohydrates; namely, carbon, hydrogen, and oxygen. Here, however, there is a much larger relative amount of carbon present and, consequently, much less oxygen than in the carbohydrates. Some fats are liquid and others are solid even at rather high temperatures, depending upon their composition.

Fats as Food. Fats are extremely concentrated foods, so far as the production of energy is concerned. For a given weight, these substances furnish more than twice as much energy in the animal body as the same weight of either carbohydrates or proteins. This group of nutrients, in general, does not appear so abundantly in the food supplies of plants and animals, as do the carbohydrates; at times, however, fats form important reserves in storage organs, as in nuts, castor-beans, and the fatty tissues of animals. With the higher animals, especially man, fats occupy an important place in the diet; in fact, they are quite necessary for the maintenance of the body in the best physical condition.

Source of Fats as Food. The chief source of this nutrient is from the animal kingdom in such foods as milk, butter, fat meats, lard, and eggs. Vegetables also contain some fat, although, at first

sight this fact is not very apparent. Some of our cereals, such as oat breakfast food, contain over six per cent, and refined wheat flour nearly one per cent. Even fruits, as grapes and strawberries, contain small quantities of fats. Thus man gets, in the aggregate, a considerable amount of this nutrient from sources where one would scarcely expect to find it.

Proteins. General Nature. Protein is the name applied to a very large group of extremely complex organic substances composed chemically of carbon, hydrogen, oxygen, nitrogen, and sometimes phosphorus and sulphur. Good examples are found in the albumen of eggs, the lean of meat, and the gluten of flour. Proteins differ from the other nutrients in being the only group that contains nitrogen and certain other elements which are present in living substance. This fact makes it clear why these food substances are absolutely essential for the maintenance of life.

Physical Characters of Proteins. Proteins differ much in solubility. Some, like part of the albumen of the hen's egg, are soluble in water; others, such as the gluten of wheat, form a sticky mass; while still others are practically insoluble in water, as in lean meat. Many proteins, such as the white of egg, are coagulated by heat, thereby forming a firm mass.

Occurrence of Proteins. In plants, proteins sometimes occur in solution in the living cells, and at other times they are found in definite crystals or granules. In beans, solid masses of protein appear mixed with the starch in the cells of the cotyledons; in certain cereals, as in wheat, for example, it occurs scattered throughout the kernels. Animals furnish large supplies of this nutrient in the lean meats, milk, and the white of egg.

Proteins and Protoplasm. The all-important living substance, known as protoplasm, consists of a very complex mixture of proteins. This living matter is essentially the same in all forms of life, and differs but little wherever found. It may be seen, therefore, that proteins from this source are of universal distribution in living things, and that they occur to some extent in all plant and animal tissues.

The Complexity of Proteins. Proteins are so complex chemi-

cally that it is very difficult for the general student to gain an adequate idea of them. Yet they are so very important as food substances for both plants and animals, including man, that they should be studied with great care. It has been stated that starches and fats are rather complex in comparison with the sugars; but even the simplest proteins are far more difficult to understand from the chemical point of view than any of the other nutrients. A chemical formula for hemoglobin, a comparatively simple protein of the blood corpuscles, gives 2378 atoms to the molecule. The fact is that many of the proteins met with in food and in our bodies are so complex that even the expert chemist has difficulty with them.

Origin of Proteins in Plants. The sugar produced by green plants through photosynthesis forms the basic substance for the production of protein. Various cells of the plant are able to take sugar and with it nitrogen, and often phosphorus and sulphur, and out of these to build up proteins. As the source for the last named elements, simple substances from the soil, such as nitrates and phosphates are utilized. This process of protein building by plants has a definite bearing upon the general problem of the fertility of the soil. It is a notable fact that in general two of the elements found in proteins — namely, phosphorus and nitrogen — are the ones most frequently lacking in worn-out soils.

Proteins as Food. Proteins are absolutely essential in the food supply of all animals and plants. No living cell can exist for any length of time without a source from which to obtain this nutrient. Plants alone have the power to build up proteins out of simple inorganic compounds; consequently, it is clear that these forms of life must provide this nutrient, not only for their own use, but for all animals, either directly or indirectly.

Proteins Occur with Other Nutrients. The proteins used by man as food are obtained from either plants or animals. In the plants, these substances are found in connection with the other nutrients. The table below, quoted from a bulletin ¹ that gives the percentage composition of foods, will serve to make this point clear.

¹ *Principles of Nutrition and Nutritive Value of Food.* Atwater, U. S. Department of Agriculture.

	<i>Proteins</i>	<i>Carbohydrates</i>	<i>Fats</i>
Dried beans	22.5%	59.6%	1.8%
White flour	11.4%	75.1%	1.0%
Corn meal	9.2%	75.4%	1.9%

Small amounts of water and ash are also present. Proteins from animal sources are often more abundant, relative to the carbohydrates present, than is the case with plant products.

	<i>Proteins</i>	<i>Carbohydrates</i>	<i>Fats</i>
Round steak	19.0%	—	12.8%
Hen's eggs	13.1%	—	9.3%
Milk	3.3%	5.0%	4.0%

Large amounts of water and small quantities of non-digestible materials are in these animal foods.

DIGESTION OF FOODS — ENZYMES

Changes in the Form of Foods. From the preceding discussions, it is clear that foods occur in forms that are not suitable for use in the bodies of plants and animals. Many of them when stored are insoluble, and consequently must be made soluble before they can pass into the sap of plants or the blood of animals to be carried to the organs where they are needed. Even though the nutrient be soluble, it must

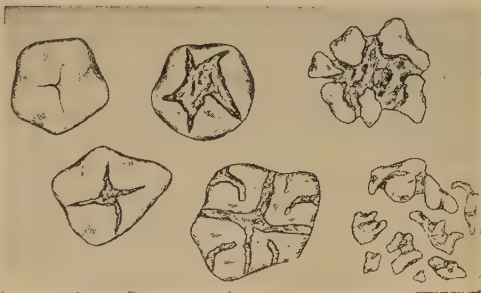


FIG. 34. — DIGESTION OF STARCH

The starch grains were taken from a kernel of germinating corn and show the results of enzyme action. (Original)

often be changed to a simpler form before it can be used, as is the case with cane sugar and some soluble proteins.

Germination and Food Changes. As was pointed out in the discussion of germination, the food stored in the cotyledons of the bean and in the endosperm of corn disappears from these structures

and is used for the nourishment of the seedling during its development. The removal of the food from these tissues is made possible through changes that take place in its solubility. Even to the naked eye there is evidence of the loss of food from these structures; for the cotyledons soon wither and drop off in the bean, and the kernel becomes soft and rots in the corn.

Further Evidence of Food Changes in Germinating Seeds. Under the microscope, the changes in the corn starch of the germinating kernel is indicated very clearly by the dissolving of parts of the starch grains. (Fig. 34.) This gives rise to small particles



FIG. 35.—DIGESTION OF STARCH IN BANANA CELLS

Left — Cells from a green banana showing large starch grains. *Right* — Cells from a very ripe banana with grains much reduced. (Original)

which later disappear completely. Chemical tests for the nutrients are also instructive. The dry kernel does not show the presence of glucose, but when germination is taking place there is an abundance of this nutrient

present. Growing roots and shoots of corn seedlings do not give the test for starch, but the reaction indicating the presence of simple sugars is easily obtained from them.

Definition of Digestion. *Digestion, whether in plants or animals, consists in the chemical changes in foods that make them available for use in the living body.* These changes reduce more or less complex substances to simpler forms. Insoluble substances are, by this means, made soluble. This is well illustrated by the digestion of starch in the human body. Here we find a substance that is quite complex and virtually insoluble, reduced by the action of the saliva and pancreatic juice to a simple sugar, which is not only soluble but also suitable for use in the tissues.

Agents of Digestion. Digestion in both plants and animals is brought about through the activity of substances known as enzymes. These are found in all digestive fluids in animal bodies, including man, and are also widely distributed in plant tissues. In fact, wherever living organisms bring about chemical changes in foods or in other organic substances enzymes are very generally involved.

Character of Enzymes. Enzymes are substances produced by the living protoplasm, and are able, under suitable conditions for their actions, to bring about rapid changes in a wide range of food and other materials. They are looked upon as being able to *aid, or increase the rate of*, reactions that ordinarily take place very slowly. Enzymes do not become a part of the final products produced in such reactions. For example, when corn germinates, enzymes are formed in the kernels and act upon the starch present, thus producing the sugar which is used by the developing embryo. These substances may be obtained in soluble form from germinating barley or other grains. If placed in a test tube under proper conditions, they are able to change indefinite quantities of starch into simple sugars, and, since they are not used up in the process, they may be regained at the end in almost the original quantity.

Enzyme and Chemical Actions Compared. The behavior of an enzyme when it acts upon a substance is very different from that of ordinary chemicals. In the latter, the reacting materials very gen-



FIG. 36. — THE ACTION OF SALIVA UPON STARCH

Left — The test tube contains water in which is some cooked starch. *Right* — The test tube contains the same materials plus some fresh saliva. Both tubes were allowed to stand for a short time in a warm room. The clear solution indicates that the starch has been made soluble. (Original)

erally disappear and become embodied in the new substance. If, for example, oxygen and iron react chemically, a new compound, iron oxide (rust) is formed, and both the oxygen and iron disappear as such. On the other hand, if the enzyme *ptyalin*, from the saliva, acts upon starch, a sugar is formed from the starch and the enzyme remains unchanged.

Importance of Enzymes in Living Things. These substances are of the greatest importance in all living bodies, whether animal or plant. The entire digestive process in man and the lower animals is essentially a succession of chemical changes wrought by a large series of enzymes present in the various fluids that act upon the foods. Other processes in the animal body that have to do with the storing up of food, and the final use of these substances in the tissues, are involved with enzyme action. All chemical changes occurring in the food substances of plants, such as the storing up and removal of food in roots, stems and other structures; the ripening of fruit; alcoholic and other fermentations; the decay of organic matter; and numerous other related processes, are in large part dependent upon enzyme action. In short, the life processes of all living things are inseparably involved with the activities of enzymes.

Production of Enzymes. These substances are always produced by the living protoplasm, and hence are found in connection with the animal or plant body. Apparently any cell is able to produce enzymes, but sometimes, especially in the animal, certain cells are grouped together forming *glands*, whose special function is to secrete fluids, such as the saliva and the gastric juice, which contain various enzymes.

Kinds of Enzymes. The number of enzymes known to exist is very great. Those that have to do with the important food substances alone are so numerous that little more can be done here than simply to call attention to their existence. It is sufficient for the present purposes for one to understand that there is a great number of enzymes, that their action is complex, and that each definite substance is apparently acted upon by a single enzyme which does not affect any other substance; or, as is often said, *enzymes are specific in their action*.

Nature of Enzymes. *Chemical.* But little can be said of the chemical nature of enzymes. Much has been determined as to the results produced by them, and also concerning the influence of various physical and chemical agents upon them, but as to their real nature, little is certainly known. Some authorities think that they are protein in nature, but others question even this. This lack of knowledge is due in part to their very complex nature and to the difficulty of obtaining them in pure form, on account of their sensitiveness to heat and other agents.

Physical. Enzymes are frequently soluble in water, and hence they may often be extracted from sprouting grain or other tissue where they occur by treating the material with water and then filtering. Heat has a marked effect upon them. A moderate degree, say 90° F. to 100° F., enables them to act very rapidly, while a lower temperature, or one much above 100° F., generally retards their activity. Enzymes are destroyed by temperatures of 130° F. to 140° F.

Action of Enzymes. Just how enzymes cause the changes attributed to them is not entirely clear, but the results of their action are quite well known. The action, as ordinarily observed, is one that reduces complex substances to simple ones. For example, starch is a complex substance from the chemical standpoint, and the enzymes that act upon it transform it into sugar, a much simpler form of carbohydrate. Likewise, the ordinary proteins that are found in plants and animals are reduced into simpler forms much as the starches are. This, apparently, may be brought about in one step, or it may be a gradual step-like reduction, as is the case when starch is changed to dextrines, then to maltose, and finally to glucose in the human body. It should be added, however, that under certain conditions enzymes are concerned in building up complex substances from simpler types, as for example, in the various tissues of plants where sugar is changed into starch for storage.

RESPIRATION

Air and Growth. In the discussion of germination, it was pointed out that air is absolutely necessary for the growth of the seed. This condition is true not only in the development of the

seedling, but it is the same wherever growth occurs in higher plants and in animals. The presence of air or, more explicitly the oxygen of the air, is definitely connected with the use of food for energy and for the formation of new tissues.

Energy and Growth. That the so-called warm-blooded animals, such as our common domestic forms, need a continual supply of energy is very apparent to everyone, because of the heat necessary to maintain the constant temperature of their bodies. The physical movement that occurs so constantly in the lower forms, as well as in the higher, also indicates the same thing. The fact that energy is just as necessary to life where there is little or no movement, and where the temperature is essentially the same as the surroundings, is not so apparent; nevertheless, it is just as true. This is explained by the fact that energy is necessary in all growth processes which, in general, involve the formation of new living matter out of food.

Food the Source of Energy. As has been previously stated, organic food is the source of energy for animals and plants. The procuring of food, and its digestion and distribution in the bodies of plants and animals, are really preliminary steps that lead to fundamental processes concerned with obtaining energy from the nutrients and the building of new substance. It follows that the mechanism by which animals and plants are able to procure this energy from foods is of the highest importance. This brings us to the discussion of that universal process in all plant and animal forms, known as *respiration*.

Definition of Respiration. *Respiration consists of a series of chemical changes within the living tissues whereby food is broken down and energy is released.* The fundamental result in the entire process is the *release of energy*. This result is brought about through changes in food substances and is accompanied by the formation of simple compounds, such as carbon dioxide, water, and others.

Kinds of Respiration. There are two types of respiration that occur in living things. The most common, and the one met with in higher plants and animals, *requires free oxygen* which is obtained, directly or indirectly, from the air. The other type of respiration,

which takes place in the *absence of free oxygen*, is common among the lower forms of plants, notably the yeasts and bacteria. In the former, food substances are *broken down completely* into carbon dioxide, water, and other simple compounds; in the latter, food substances are but *partially decomposed*, and often alcohol, certain acids, and other complex substances are produced.

Results of Respiration. There are three results that may be expected wherever respiration occurs: 1. The release of energy in some form; 2. The decomposition of some sort of food; and 3. The appearance of comparatively simple waste products.

Energy: Its Definition and Its Forms. Energy has been defined as the power to do work. Probably a clearer understanding of the real meaning of the term may be gained by a review of the forms in which energy manifests itself. Five are usually mentioned: namely, *motor energy*, *heat*, *light*, *electricity*, and *chemical energy*. It is apparent that motor energy, heat, and electricity may overcome resistance and do work, such as the lifting of a weight or the moving of an automobile or a trolley car; but it is equally true that the form known as chemical energy, which manifests itself in a striking manner in such reactions as the explosion of gun powder, may accomplish the same results.

Transformations of Energy. The forms of energy are so related that one may be changed into another with ease. In fact, these transformations are constantly taking place about us. Broadly speaking, machines are mechanical contrivances that transform or modify the intensity of energy. An ordinary steam engine offers a good illustration of these facts. The coal used as the fuel contains chemical energy which appears as heat in the fire box. A portion of this heat is communicated to the water in the boiler and produces steam under pressure, which, acting through the mechanism of the engine, results in movement. Thus the chemical energy of the coal is transformed into heat and finally into energy of motion. Furthermore, to make the illustration more complete, the motor energy of the engine may be communicated to a dynamo and there transformed into electricity, which, in turn, may be carried over wires and changed back into the other forms, as occasion may demand,

through the various electrical appliances, such as the arc lamp, the electric heater, and the motor.

Conservation of Energy. The principle of the "conservation of energy" refers to the notable fact that in the various transforma-



FIG. 37.—FIBROUS ROOTS OF A GRASS
(Original photograph)

tions no energy is created or destroyed. Although one form of energy may appear to be destroyed, yet it does not cease to exist. For example, when a nail held upon an anvil is struck many times with a heavy hammer, the energy of motion is apparently destroyed, but in fact, it is transformed largely into heat as is indicated by the temperature of the nail. Moreover, the person who wielded the hammer did not create the motor energy, but simply transformed it from the chemical energy of the food utilized in the muscles. The food, in turn, received its supply from the sunlight, when these substances were made in the green plant.

An understanding of the principles briefly discussed above is of the highest importance in gaining a correct idea of the true meaning of respiration.

The Release of Energy in Respiration. The release of energy in respiration is always accompanied by the breaking down of some food substance. When carbon dioxide and water combine in the green leaf, thus forming sugar, as was pointed out in Chapter I, a certain amount of energy from the sunlight is absorbed in the process and is transformed into the chemical energy of the food substance. The sugar thus formed may be changed into starch, or it may form the basis for the production of fat or pro-

tein. In these changes, however, the energy is not lost; hence it is clear that any one of the organic nutrients contains a store of chemical energy that may be released by the plant under suitable conditions.

When these foods are brought into contact with the living substance in the process of respiration, they are broken down either directly or indirectly, into comparatively simple substances, such as carbon dioxide, water, and others. Since these end-products contain no available energy, or at least a smaller amount of it than the original food, some energy must be set free in the process. These complex changes probably are brought about through the agency of enzymes produced by the protoplasm of the cells where the processes take place.

Energy and Activity of Organisms. Every living thing must have a constant supply of energy. The only possible exception may be certain resting structures, such as dry seeds, spores, and the like; but even here it may be that minute quantities of energy are supplied to sustain the life of the protoplasm. The amount of energy necessary for life depends largely upon the

activity of the organism. Plants or animals that are growing rapidly, or that are moving about vigorously, or that maintain a high body temperature must have an abundant supply of energy. As the growing organism becomes less active, smaller and smaller amounts



FIG. 38.—PLANTAIN, A SO-CALLED "STEMLESS" PLANT (Original photograph)

are demanded, until—in the resting stages noted above—only the minutest quantities, if any at all, are needed to keep the organism properly nourished.

Respiration in Animals. Respiration, in some form, occurs in all living things. This follows from the facts, first, that a supply of energy is absolutely essential for every living organism, and second, that this energy can be provided in the living body, in general, only through the decomposition of food in the respiratory



FIG. 39.—TAP ROOTS (Original photograph)

process. In the higher animals, such as those which possess gills or lungs, it is generally recognized that respiration continually takes place, but the same holds true in the simpler forms, such as worms and the tiny protozoans found in stagnant water, that have no special organs adapted for taking in oxygen. In these cases, the

oxygen passes through the moist surface of the body into the living tissues where the breaking down of the food takes place.

Lungs in Relation to Respiration. Respiration, as it occurs in man and other lung-breathing types, is essentially the same process as that found in the simple animal forms and in most plants. The presence of lungs in no way changes the fundamental process that takes place in the living cells of the body. These organs, as well as the circulating blood, are important in human respiration, in that they supply the living tissues with oxygen, and also enable the body to rid itself of carbon dioxide. It should be understood that



FIG. 40.—CLIMBING ORGANS OF PLANTS

Left—Tendrils of Japanese ivy. *Right*—Roots of poison ivy. (Original photograph)

the lungs, important as they are to the maintenance of life, are simply the means that make respiration possible. The fundamental end of respiration in man, as in other organisms, is the *release of energy in the living tissues*, thus making possible the carrying on of the life processes.

Respiration in Plants. Seeds. Germinating seeds show very definite indications of the respiratory process. In this condition they are very active, and consequently, utilize much energy in carrying on the growth processes. It is to be expected, then, that respiration is vigorous in such structures. It is an easy matter to show that oxygen disappears from the air in a bottle of germinating seeds and that the carbon dioxide content increases. With suitable apparatus to provide against loss, it is not difficult to demonstrate also

that energy, in the form of heat, is released as the seeds grow. Another observation that may be made is that of the loss in dry weight of seeds during the process of germination. With these structures, then, we have the opportunity to observe to advantage the various results connected with respiration.

Air Spaces in Plants. Just as free oxygen is essential for the germination of the seed, so it is necessary for the growth of the living tissues of the plant body, in general. Thus spaces, more or less directly connected with the external air, are common in many higher plant tissues. This is true to a remarkable extent in certain water plants where such structures as stems grow continually beneath the surface. Here the internal structure is often modified so that oxygen may reach all active tissues through definite air passages. In lower forms, such as the pond scums, or *algæ* as they are called, the oxygen is absorbed directly from the water. With all green plants, as is pointed out in Chapter VI, the release of oxygen in the process of food-making obscures the results due to respiration occurring at the same time.

CHAPTER V

ROOTS AND THEIR RELATION TO THE SOIL GENERAL NATURE OF ROOTS

Functions of Roots. Roots of higher plants have three important functions: 1. The absorption of water and other substances that the plant needs; 2. The storage of food; and 3. The anchorage of the plant to the soil, enabling it to grow upright. The most fundamental of these functions is the absorption of materials. The other functions vary in importance with the different types of plants. In some, such as the radish and parsnip, the large central root is modified and serves expressly for food storage; while in other cases, as with peas and corn, the roots appear to be of little use in this way. Likewise the anchorage is very important with plants that must be held upright in the air, as with our trees and the grains, while with others, such as various vines and trailing plants, this function is less marked.

Kinds of Roots. The roots of most plants grow in the soil, but sometimes they are found in the water or even in the air. The grass roots such as are found in the blue grass sod are good examples of *soil roots*. *Air roots* or *aerial roots*, as they are sometimes called, are found in poison ivy and certain other vines, where they serve to hold the slender stems to the tree trunk. Some of the most interesting examples of these aerial roots are the brace roots of corn that appear as air roots and then, when they reach the soil, function as ordinary soil roots. *Water roots* are often found in water plants, as in the common duck weed and other floating forms.

Forms of Roots. Roots are of various forms, as one will find if he examines these structures on a dozen different species of plants. Many of them, notably the grasses, have very slender, more or less branched roots known as *fibrous roots*. These, when abundant, are likely to hold the soil particles together, thus forming a sod. In

others, such as the sweet potato and dahlia, some of the roots become storage organs, and consequently are of large size and of a fleshy nature due to the large amount of food present. Other roots of these plants are fibrous and function in absorption. (Figs. 37, 38, and 39.)

Roots of Trees and Shrubs. Many plants, such as our trees and shrubs, have roots of a woody nature. These roots serve to some extent for food storage, but are probably of greater value in transporting the sap absorbed near the growing tips to the body of the tree. Woody roots doubtless serve a valuable end in holding the plant erect. Tree roots often are of large size, and extend for long distances through the soil. Examples of such may be seen to advantage along almost any wooded stream. (Fig. 42.)

In some plants there is a main central root of comparatively large size called the *tap root*. This generally extends straight down into the soil, and from it smaller roots extend out at various angles. Often, as with parsnips, carrots, and others, the tap root becomes large and fleshy due to the abundance of food stored in it which is used later by the plant when the seeds are maturing. (Fig. 39.)

Development of the Root System of Corn. A careful study of the development of the root system of the corn plant will serve to bring out certain important facts relative to plant roots in general. If kernels of corn are placed in moist clean sand or sawdust and studied from day to day, very rapid changes may be observed. In a very few days, under advantageous conditions, the radicle breaks through the coats and gives rise to a root that grows downward at a surprising rate—sometimes an inch or more in a day. By the time this root reaches a few inches in length, secondary roots appear and grow out almost at right angles, thus coming into contact with vast numbers of soil particles. (Fig. 30.)

While this first root is developing as described above, a number of others appear from very near the kernel and grow out at various angles into the soil. These also develop very rapidly and soon produce numerous branches that materially add to the extent of the system. In the meantime, the plumule has given rise to the shoot which now has reached the surface and opened out into the first

leaves. From this shoot, not far above the kernel and generally near the surface, a third group of roots appears and develops as in the other cases. At this stage the seedling is mature; that is, the stored food has been used. Henceforth the plant must depend upon photosynthesis to furnish subsequent supplies. Consequently, about this time the corn plant is sometimes said to "stand still." In



FIG. 41.—A TANGLE OF ROOTS EXPOSED IN A CREEK SHOWING HOW SOIL IS OFTEN HELD IN PLACE BY SUCH ROOTS (Original photograph)

reality the plant is growing, although not making such striking advances as before. The production of food which takes place rather slowly at first, increases as the plant gets larger.

The Root System of a Mature Corn Plant. As the corn plant approaches maturity, three kinds of roots become prominent. 1. The *main vertical roots* arise from the base of the stem and, curving outward slightly, pass almost directly downward to a depth of three feet or more under favorable conditions. These give off large numbers of branches that bring the plant into intimate contact with the deeper layers of the soil. 2. The *main lateral roots* leave the base of the stem, curve slightly downward, and then grow almost

horizontally, only a few inches beneath the surface of the soil. These, as with the vertical roots, throw out many fine branches and literally fill this portion of the soil with tiny roots. The lateral roots are of the highest importance to the plant, for they penetrate the most fertile parts of the soil. These are the roots that are most



FIG. 42. — ELM ROOTS PARTIALLY EXPOSED IN A CREEK

The large horizontal root is visible for thirty feet and doubtless extends into the soil for many feet more. (Original photograph)

likely to be injured during the cultivation of the plants. 3. The *brace roots* originate above the surface of the soil and strike downward at an angle reaching the surface a few inches from the base of the stalk. When they enter the soil, they branch as do the others and doubtless function for absorption as well as for holding the plant erect. These facts are clearly shown in Figure 3.

The Extent of Root Systems. Plants in general have very extensive root systems. That of the corn has already been discussed in Chapter II, but in many other plants the root systems are just as remarkable. Trees and smaller woody plants whose roots are exposed along the banks of creeks often furnish excellent examples for class study. (Figs. 41 and 42.) An understanding of

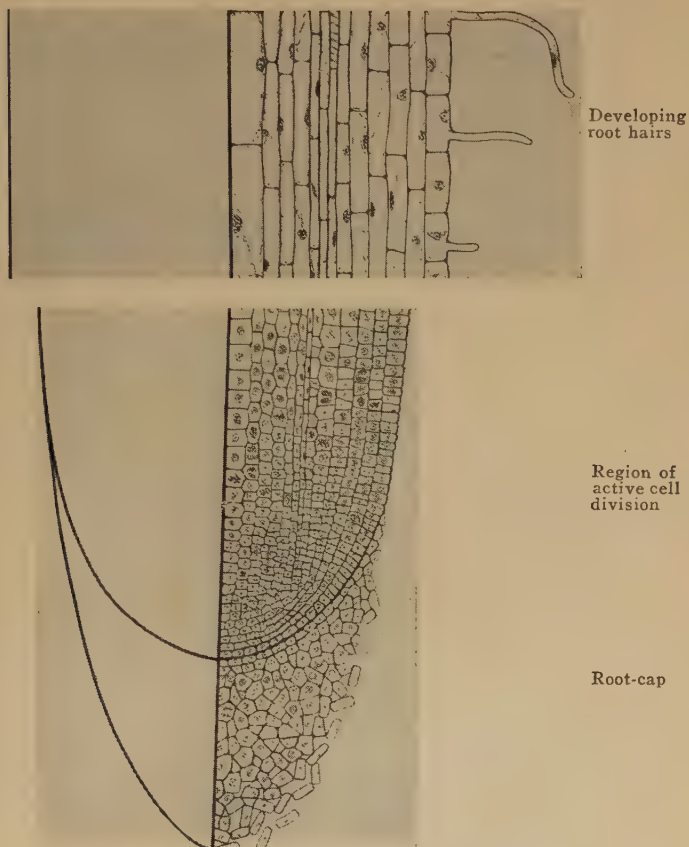


FIG. 43.—ZONE OF GROWTH IN A ROOT-TIP

Longitudinal section through the center of a root-tip of onion showing the character and arrangement of the cells. The upper figure represents the cells several millimeters back from the tip; the lower, those near the extreme tip. (Original. Slightly diagrammatic)

this general fact is of importance in the transplanting of trees or other plants, for so great is the spread of the roots, even of a small specimen, that it is often difficult or even impossible to avoid cutting many of them when the plant is dug up. (The student should discover several ways in which extensive root systems are injurious or valuable to the farmer and gardener.)

Structure of Roots. **Root Cap.** The tip of the root, or *root*

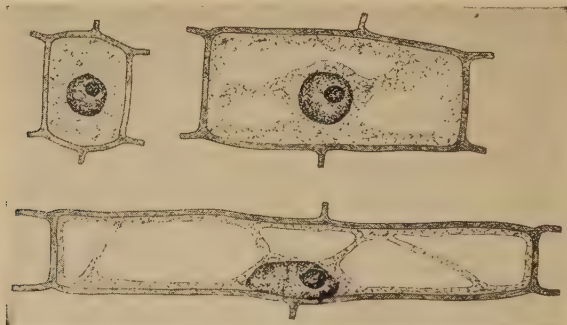


FIG. 44.—PLANT CELLS SHOWING THE FORMATION OF VACUOLES AND CELL ENLARGEMENT

Upper left—Cell just after division. *Upper right*—Cell enlarged and showing the formation of water vacuoles. *Lower*—Cell much elongated showing how the protoplasm is often distributed in plant cells. (Original)

cap, as it is called, consists of loose cells the surface layers of which easily break off from the more compact portion beneath. The internal structure of the root tip is shown in Figure 43. As the tip is forced through the soil by the lengthening of the root a little farther back, these loose cells slough off and as they are continually added to from beneath, they prevent the very tender growing tissues near the tip from being injured by contact with the soil particles.

The Zone of Growth. Just above the root cap, and extending for a considerable distance, is the *zone of growth*, or in other words, the portion of the root where the increase in length takes place. A careful study of Figure 43 will serve to make clear what occurs in this region of the root. Just back of the tip, a group of cells, or in some cases a single cell, retains the power of division indefinitely,

and continually gives rise to cells that are added to those already formed. These new cells rapidly elongate and cause the root to lengthen with great rapidity. This process causes the root cap and the group of cells just back of it, that are actively dividing, to be pushed forward through the soil. Thus it is clear that the growth in length of a root takes place very near the tip.



FIG. 45. — SAND PARTICLES ADHERING TO ROOTS (Original photograph)

Formation of Root Structures. After the cells of the root tip attain a certain size, changes take place that finally result in the formation of the specialized structures of the body of the root. Some of the cells form the *ducts*, or tubes for the carriage of the sap, while others may serve for food storage. Likewise some may retain the power of division and add new cells to the root in a way to increase the diameter, while still others may form tissues of an

entirely different nature. In brief, in this region, generally within an inch or two of the tip of the root, the newly-formed cells that at first are all alike gradually become transformed into the mature plant tissues. (Fig. 44.)

Root Hairs. Root hairs are extremely delicate outgrowths of the surface cells of the root, and are situated a short distance back of the tip. They are minute in size and occur on the roots in countless numbers, forming a velvety coating extending for as much as an inch or even more in rapidly growing roots. They are so delicate that

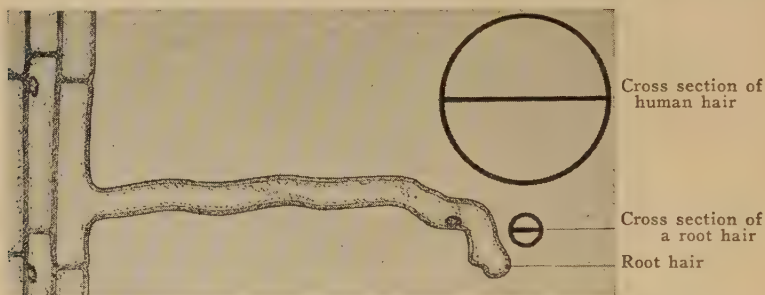


FIG. 46.—SIZE AND STRUCTURE OF A ROOT HAIR

The human hair and the root hair are each magnified to the same extent. Note the distribution of the protoplasm within the hair and the cell of which it is an outgrowth. (Original. Somewhat diagrammatic)

any slight disturbance, such as a breath of dry air, or a slight mechanical strain of any sort will destroy them. When a root is pulled out of a very loose, mellow soil, the fine particles entangled among the root hairs often adhere to the roots in considerable quantities, but if the soil is more compact the hairs will be broken off. In either case it is very difficult to see the root hairs.

Structure of Root Hairs. The root hair is essentially a slender tube more or less distorted by contact with the soil particles. Within, a thin layer of protoplasm lies against the walls forming a complete lining of the root hair as well as of the cell of which it is an outgrowth. Somewhere within the hair, or the cell of which it is a part, a nucleus is found. The large central cavity of a mature root hair is filled with water in which various substances are dis-

solved. These facts are of great importance when considered in relation to the absorption of water and other substances. (Fig. 46.)

The Origin of Root Hairs. Root hairs appear just above the rapidly growing tip of the root, at first as minute projections from the surface cells. These rapidly elongate and extend out into the soil for a few millimeters at about right angles to the root. Consequently this portion of the root comes to be in very close contact with soil particles because of the hairs that penetrate between them in the most intricate fashion. This growth takes place rapidly and the hairs may attain their maximum length in a few days.

Length of Life of

Root Hairs.

Root hairs are often short-lived. In corn and other seedlings they reach full size, and soon begin to wither, and in a few days at most nothing remains of them. As a result of the continual addition of new root hairs near the tip, and the constant dying off of these structures farther back, the portion of the root that bears the root hairs, known as the *zone of root hairs*, advances through the soil, keeping pace with the growth of the tip. This constant

advancing of the root hair zone is of importance, for in this way the growing plant is able to draw upon new portions of the soil for the water and minerals that it needs.

Function of Root Hairs. The water and mineral substances that enter the plant are absorbed by the root hairs and the surface cells of which these are outgrowths. In ordinary soil, the hairs are

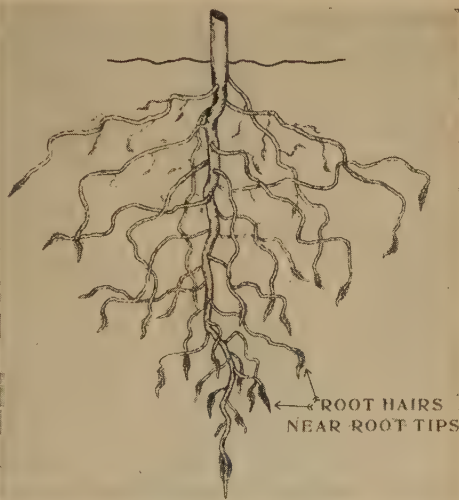


FIG. 47. — ROOT SYSTEM SHOWING THE OCCURRENCE OF ROOT HAIRS (Somewhat diagrammatic. From a wall chart by the author)

by far the most important in this work, but under certain conditions, such as excessive moisture, these do not develop in very great abundance, and then absorption takes place largely through the surface cells of this region.

Passage of Water through Roots. The absorbed substances pass through the surface layers of cells into the interior of the rootlets and find their way to the tubes, or ducts, through which they pass upward to the parts of the plant above the soil. The older portions of the roots of most of our land plants soon become covered with corky tissue that prevents the escape of water from the inside as well as its entrance from the outside. Were this not true the water obtained from the deeper layers of the soil during droughts would be lost in its passage through the dry surface portions of the soil, and consequently the plant would suffer.

The Transplanting of Plants. These facts — that water enters the plant near the tips of the roots at considerable distances from the base of the stem, and that the absorbing organs, or root hairs, are very easily broken off or destroyed in other ways — are extremely important factors relative to the transplanting of growing plants. In the removal of a plant from the soil, more or less injury that will later interfere with the absorption of water is certain to result. If the plants are small and taken from the soil without special care — as is often the case with various vegetables and flowers, such as cabbage, lettuce, asters, and pansies — the root hairs are either broken off or come into contact with the dry air and are destroyed. When considerable dirt is taken up with the young plants, the injury done is not so great; but even in this case the root systems are likely to be damaged. If the plants are large, such as young fruit trees, the roots extend for considerable distances, and many of them must be cut, and consequently, the absorbing surfaces are largely lost.

Loss of Water in Transplanted Plants. Many plants, if given a fair chance, will readily produce new root hairs and rapidly regain the ability to take in sufficient water. The great danger lies in the fact that water is lost very rapidly through the green leaves and young stems, and that frequently this loss is so great that the

plant dries out and dies before new root hairs can be produced in sufficient number to provide for the deficiency. Often in plants that have been reset, the older leaves wilt and die and thus the loss of water is reduced. In dry, warm weather, however, plants, whose root systems have been disturbed, are likely to die unless care is exercised to prevent their drying out..

Precautions to be Taken in Resetting Plants. An abundance of water upon reset plants is of advantage if the physical character of the soil is not injured by such treatment. (See Puddling of the Soil, Page 116.) This makes possible maximum absorption and thus enables the plant to produce new roots rapidly. Plants should not be set in soil that is wet and soggy; for although sufficient water may be obtained under these conditions, yet if dry weather follows, the earth about the roots is very likely to become hard and compact and so hinder the subsequent growth of the plant. Sometimes some of the older leaves are removed from the plants that have been reset, or the plants are covered with jars, paper, and the like. Either of these methods will aid in preventing the loss of water, and will be of advantage especially in dry, hot weather.

Transplanting Woody Plants. The woody plants, such as shrubs and young trees whose roots are likely to be injured in removing them from the soil, are generally transplanted in the fall or early in the spring, when the leaves are absent; consequently, the loss of water from the plants is comparatively small. With such, there is sufficient food stored in the various tissues to enable the plant to produce new roots rapidly during the early days of spring, and thus provide for sufficient water when it is needed later in the season. Often the branches are closely pruned in such cases, a practice that is beneficial on account of the reduction of the loss of water during the early periods of growth.

Transplanting Large Trees. Sometimes trees of considerable size are transplanted by removing a large amount of earth with the roots. This may be accomplished by digging a deep ditch about the tree at a suitable distance from the trunk before the soil freezes in the late fall. During the winter when the earth is solidly frozen

about the roots, the tree is loaded upon a strong sled or other conveyance, and taken to its new position where it is set out. The



FIG. 48. — EFFECT OF INJURY TO ROOTS UPON THEIR DEVELOPMENT

Left — A plant of shepherd's purse whose tap root was cut off earlier in the year. *Right* — Another plant whose roots have developed normally. (Original photograph)

tops of such trees are often pruned closely. During the following summer much water is used upon the soil at the base of the tree. Trees eight or ten inches in diameter or larger may be transplanted in this way.

Effect of Transplanting upon the Root System. The injury to the roots of a plant due to transplanting is only temporary; in the long run, the effect is often beneficial. When a root is cut off or injured seriously, there is a tendency for it to branch profusely near the wound. (Fig. 48.) Conse-

quently when a plant is reset, the numerous roots that have been injured tend to form branches that result in the production of a much more compact root system than before. This may be easily seen if one compares the root systems of nursery stock that has been reset two or three times with those of seedlings of the same kinds that have never been transplanted.

Advantage of Transplanting. The same is true of garden plants such as tomatoes, cabbage, celery, and others. A root system that is made up of a large number of small, short roots, is easier to handle and gives better results when transplanted, than one that is made up of a few large roots that extend out a long distance and must be seriously injured when removed from the soil. For this reason, forest trees that have been grown in a carefully managed nursery are generally more satisfactory for planting, everything considered, than those taken from the wild. Likewise, reset garden plants are likely to give better results when planted out than those simply grown in rows from the seed without special care.

Effect of the Character of Soil upon Root Development. The physical conditions of the soil, such as its compactness and water content, have definite effects upon root development. Desert plants in general penetrate the soil to great depths, while those that grow in very wet soils are likely to have their roots near the surface. A loose soil offers comparatively slight resistance to the rapidly elongating and tender root tips while a compact layer often will cause the tips to curl up, or at least prevent them from developing as they would under more suitable conditions.

Soil Conditions and Root Hairs. The production of root hairs is also controlled to a considerable degree by soil conditions. Corn roots, for example, grown in a very wet soil have but few root hairs, but in a moist, mellow loam these are abundant. The occurrence of root hairs is probably related to the content of air, or, more properly, of oxygen, in the soil. If the soil is very wet, the water fills most or all of the larger pores between the particles and thus excludes the oxygen, which, we have seen, is essential for growth.

One of the most important effects of the cultivation of the soil, other than the destruction of weeds, is related to the better penetration of the air into the deeper layers. The same is also probably true relative to the improvement by the draining of water-soaked lands.

The Effect of Roots upon the Water Content of the Soil. The roots of trees and of plants in general remove large quantities

of water from the soil. In dry times this is especially noticeable where trees or hedges are growing in close proximity to a field of corn. The early rolling up of the blades of such corn is doubtless largely due to the fact that the wide-spreading roots of the larger

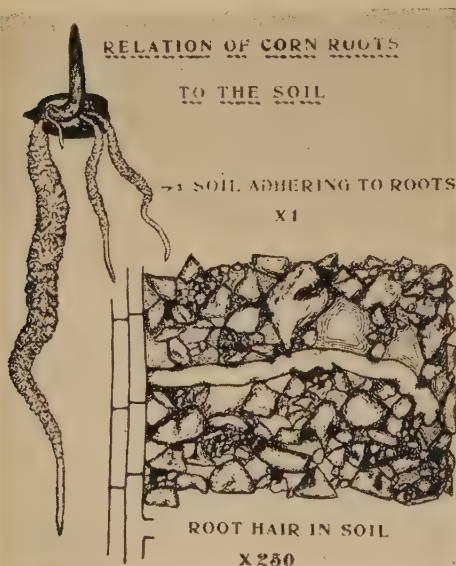


FIG. 49.— (From a wall chart by the author.
Somewhat diagrammatic)

plants remove so much water from the soil. Weeds are extremely injurious in the same way. They are generally very hardy and have numerous roots that permeate the soil in all directions to considerable depths: consequently, much water is carried up and given off through their leaves. This moisture would remain in the deeper layers of the soil were the weeds not present. In droughts, it is often the case that in a weed patch, even where the surface is protected from the direct

rays of the sun, the soil is much drier than it is in the open where there are no plants and where the sun strikes it with full force. Because of this and other effects, weeds are extremely injurious to the less hardy agricultural and garden plants.

Length of Life of Roots. *Annuals.* In many plants, such as corn, radishes, and others, the roots live only as long as the upper parts. Such types grow from the seed each year, reach maturity, and die at the approach of winter. As these plants complete their life cycles in the growing season of one year they are known as *annuals*. The roots of annuals do not function very definitely as permanent storage organs, for the food is very generally stored in the seed for the use of the embryo during germination.

Biennials. Plants like the parsnip, carrot, dock, thistle, and many others, have roots that live over winter, although the tops die at the coming of freezing weather. With these plants, the seeds germinate in the spring much as those of the annuals do, but instead of a rapid development that results in flowers and a crop of seeds the first year, much food is stored. These plants generally produce a number of large vigorous leaves and an extensive root system which finally becomes gorged with reserve foods. As winter comes the leaves die off, while the roots with their rich stores of foods lie buried in the soil. The following spring a shoot appears and often grows with surprising rapidity as a result of the abundance of available food. This shoot produces flowers and in due time matures a crop of seeds after which the entire plant generally dies. As such plants require the growing seasons of two years in which to complete their life cycles they are called *biennials*.

Perennials. In the numerous woody plants, such as trees and shrubs, both the stems and roots live year after year. The roots of such plants very often serve as storage organs, but not to the extent that is the case with many of the biennials. The main body of the tree or shrub, as well as the smaller branches, share in this function. The roots of some herbaceous plants, such as those of the dandelion and alfalfa, likewise live from year to year. With these the food is stored entirely within the root systems. Plants that live year after year are known as *perennials*.

CELLS

Definition. Upon the invention of the microscope it was soon discovered that cork, wood, and other related substances are made up of immense numbers of minute, box-like cavities. These were called *cells*. Later, as more became known of the true nature of living substance, it was found that the really important structure is not the cavity or walls, but a peculiar semi-transparent substance always present within the cavity, in living plant tissues. This *essential material* was called *protoplasm*. The meaning of the term "cell" consequently became broader in order to include all of these

structures. Now, the term is generally used to refer to the entire structure — wall, living contents, and all. In animal cells there are no definite cell walls, such as are found in plant tissues.

Cells and Living Things. The bodies of all living things are made up of cells. In the lower forms of plants and animals, such

as bacteria and the minute creatures found in stagnant water, the body is composed of a single cell; while in the higher forms, countless multitudes of cells make up the various tissues and organs. This cellular structure is well shown in the pulp of the



FIG. 50. — PLANT CELLS SHOWING CHLOROPLASTS AND THE DISTRIBUTION OF THE PROTOPLASM

Sometimes protoplasm may be seen to circulate within the cells. (Original)

banana, the cotyledon of the bean, and in a section of a root tip; in fact, a thin section from almost any plant or animal tissue serves well for this purpose. *The cell is the unit of structure in living things.*

Cells and Resistant Structures in Plants and Animals. Certain structures of plants and animals consist of the deposits formed by the living cells, rather than of the cells themselves. In plants, for example, the cells that form the wood, the shells of nuts, or the covering of certain seeds are thin-walled and tender when very young but become very hard, thick-walled, and resistant through the addition of materials from the living substance within. Likewise in animals there are many structures that are produced in a similar manner. Thus bones, shells of various sorts, and numerous other structures are hardened and made resistant by the addition of certain substances, such as lime compounds secreted by the protoplasm of the cells.

Structure of Cells. *Plant Cell.* A typical plant cell consists of a minute particle of living substances or *protoplasm*, generally enclosed by a *cell wall* of considerable thickness. Somewhere in the cell, frequently near the center, but sometimes lying against the wall,

is the *nucleus*, which is made up of a specialized portion of the protoplasm, and which has important functions relative to cell division and other activities. Within the protoplasm that lies outside of the nucleus, and known as *cytoplasm*, are small living bodies called *plastids*. These bring about certain changes such as are necessary in the storage of starch, and perform other functions of a special nature. Very often in mature cells relatively large cavities known as *vacuoles* are found. These are filled with water in which are dissolved substances of various kinds. Besides these special structures there may occur bodies such as *starch* and *protein grains*, and *oil droplets*, suspended in the protoplasm.

Animal Cell. The animal cell is quite similar to that of the plant except in regard to the *definite cell wall*. The exterior layer or covering of the animal cell seems to be made up of a more or less specialized portion of the protoplasm itself; at least it is not a clearly defined wall such as is present in the plant. It is very significant that the living cells of plants and animals are essentially similar, for it throws light upon the fact that the fundamental physiological processes—such as growth, reproduction, respiration, and digestion—are primarily the same wherever they occur in living things.

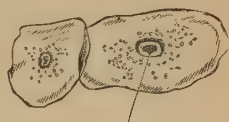


Fig. 51.—EPITHELIAL CELLS FROM THE INSIDE OF THE CHEEK

The Cell an Organized Unit. From what has just been pointed out, it will be seen that a cell is not simply a mass of living substance that in some mysterious way carries on the life processes, but rather that certain portions of the protoplasm are set aside to perform definite functions. In other words, the cell is made up of specialized parts. This organization is very much more complex than is indicated by the brief discussion of the cellular structures as given above.

The Cell Wall. Its Nature. The most permanent structure of the plant cell is the *cell wall*. (Fig. 50.) In fact, this is the part of the cell that generally remains as a permanent structure after the living parts have disappeared. Consequently the cell walls, together with resistant materials that are added to

them by the living protoplasm, make up such important structures as wood, cork, fibers of various sorts, and numerous other plant products.

Cell Walls Determine Character of Tissues in Plants.

If one examines various tissues of the plant under the microscope, he will see at once that the type of cell wall of which the part is composed really determines the character of the structure. In hard wood, for example, the cells are thick-walled and very resistant, suited to give rigidity and strength to the structure; while in cork they are thin and pliable, thus contributing the soft spongy character to this material. In many tissues specialized for storage, such as the endosperm of corn, or the storage cells of the Irish potato, the walls are extremely thin and delicate; consequently, these structures lack the tough or resistant character so common in plant tissues.

Composition of Cell Wall. The cell wall, in general, is composed of a substance known as *cellulose*. This occurs in almost pure form in cotton fiber. Although it is a carbohydrate, closely resembling starch in chemical composition, it is much more resistant to digestion than the starches and sugars. In fact, man cannot use it at all as food.

Cellulose and the Diet. Cellulose, which is very abundant in plant tissues, makes up the great mass of indigestible portions of many green vegetables, such as turnips, parsnips, and celery. One of the great values of these foods in human diet is due to their bulky nature. The large amount of refuse that remains after digestion aids greatly in the healthy functioning of the intestines, and is a factor of high importance in health.

Protoplasm. Its Nature. Protoplasm is a very complex mixture of proteins, so difficult of analysis, indeed, that no one can tell just how it is built up. Somehow in this complicated substance those activities that we refer to as the life processes — such as growth, reproduction, respiration, excretion, and others — originate and are carried on. Living protoplasm constantly builds itself up out of non-living food and as continually breaks down into simple waste products. This ever-continuing change in the protoplasm,

which is the most fundamental characteristic of the living substance, separates it definitely from non-living matter. It is doubtful whether these changes ever cease in living matter, even in stages where the protoplasm is in the resting state.

Appearance under Microscope. Protoplasm, as it generally is found in the plant cell, is a granular, semi-transparent substance rather difficult to see with the microscope unless under the most favorable conditions of light. With the exception of the nucleus, which is generally firmer, it may be described as a semi-liquid, more or less jelly-like mass. In certain cells the protoplasm may be seen to move sluggishly, carrying along chlorophyll bodies or other structures.

Protoplasm in Plant Cells. Plant cells that are full grown generally contain relatively small amounts of protoplasm, often distributed as a thin lining just within the cell wall. The nucleus is frequently contained in a small mass, either against the cell wall or toward the center, and connected with the layer near the wall by strands of the living substance. These points are clearly shown in Figure 44. In newly-formed plant cells, such as those near the growing point of the root (Fig. 43), the protoplasm is relatively much more abundant than in the older tissues.

Nucleus. The nucleus is an essential part of every typical cell and performs functions of the highest importance. If the nucleus ceases to exist, the cell soon degenerates and dies. Within the nucleus is a substance, known as *chromatin*, that behaves in a most remarkable way in ordinary cell division and in the formation of the germ cells. In fact, the behavior is such that it is impossible to draw any other conclusion than that the nucleus, especially its chromatin, is vitally *concerned with the transmission of hereditary characters*.

Plastids. These specialized living bodies, scattered through the cytoplasm of plant cells, are of three kinds: namely, the *chloroplastids*, which contain the chlorophyll, the *starch plastids*, which are active in the formation of starch grains, and the *colorplastids*, which contain certain pigments. These structures are of great importance in the green plants, but are either entirely missing, or at

least are of much less consequence in the lower plants and in animals.

Vacuoles. These cavities in the protoplasm may be small and numerous — as is often the case in young cells — or they may enlarge later and run together, forming one, or a few of larger size. Vacuoles are never found empty, but contain water in which are dissolved various substances, forming what is known as *cell sap*. Sometimes the cell sap is colored, as is the case with the beet, thus giving the red color to these cells.

Cell Growth. The increase in size of plants and animals is brought about through the multiplication and growth of the cells

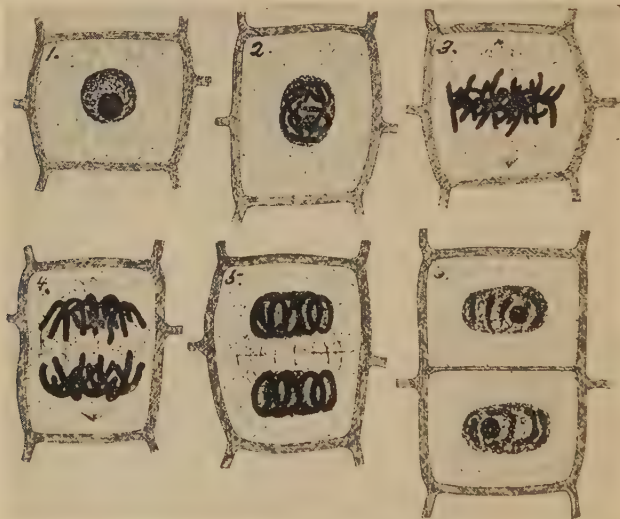


FIG. 52.—STAGES IN CELL DIVISION

1. Resting cell. 2, 3, 4, and 5. Intermediate stages. 6. Final stage. See text. (Original)

of which the various tissues are composed. The enlargement of the cell is due in part to the production of more protoplasm; but in many cases, especially with plant tissues, the entrance of water into the vacuoles results in rapid increase in size. This increase with the absorption of water is well shown in the growing tip of

a root. (Fig. 43.) This method of growth makes clear why root tips or twining vines increase in length so rapidly and why actively growing structures are so largely composed of water.

Cell Division. General Statement. Cells multiply by a process known as cell division. In tissues, such as a root tip, where this is actively taking place, the protoplasmic contents of the cell increases rather rapidly up to a certain point, and then very complicated changes begin in the nucleus that finally result in the division of this structure into two parts. The protoplasm outside the nucleus — the cytoplasm — then divides, and a cell wall forms between the parts, thus giving rise to two complete cells.

These newly formed cells may continue to grow rapidly and divide again in a short time, and thus additional cells may be produced in great abundance. In higher plants, however, only a comparatively small number of these cells retain the power to divide; by far the greater number increase in size and develop in one way or another so as to build up the various permanent tissues of the plant. For example, only a small number of cells near the tip of the root continue to divide, while the others elongate, add materials to their walls, and finally give rise to the ducts, storage cells, and other tissues found in the older part of the root. A careful study of Figure 43 will serve to make these points clear.

Stages in Cell Division in Plants. At the beginning of cell division, the nucleus is generally situated near the center of the cell, and through it are scattered particles of chromatin, a substance that colors readily when the cells are stained so as to bring out the various structures. Very soon this chromatin collects in a ribbon-like strand that coils around in the nucleus and appears, in the sections stained with an iron compound, as a heavy black band. As the development proceeds, this band breaks up into segments, called *chromosomes* that arrange themselves near the center of the cell. In the meantime, the membrane that surrounds the nucleus disappears. About the time that the chromosomes pass to the center of the cell, each splits lengthwise, thus forming pairs, the members of which seem to be identical. While these changes are going on, fiber-like strands of protoplasm radiate from two points

or *poles* in the cytoplasm on opposite sides and at some distance from the group of chromosomes in the center of the cell. These fibers form what is called the *spindle*, so named because of the general shape of the structure. The fibers from the opposite poles become attached to the pairs of chromosomes in such a way that one from each pair is drawn to each pole. These groups of chromosomes finally become surrounded with nuclear membranes and thus new nuclei are formed. It is important to note that the chromosomes that enter one nucleus are identical with those that enter the other. While these changes are taking place, new walls are formed between the two nuclei, and thus the process of division is completed. Several of the successive stages in the division of a cell from the root tip of an onion are represented in Figure 52.

Types of Cell Division. The type of cell division described above and known as *mitosis* occurs almost universally in both plants and animals. That which takes place in animals differs only in minor details. In some of the lower forms of both plants and animals, the process is modified to a considerable degree, but even here the equal division of the chromatin between the two daughter cells seems to occur. Another type of division which consists of a simple splitting of the cell into two parts occurs in rare cases.

Chromosomes in Sex Cells. In the early development of the sex cells of both plants and animals, mitotic divisions occur, and the chromatin, as a consequence, continues to be equally distributed, as has been described under cell division. At a time, however, just preceding the production of mature eggs and sperms, very remarkable changes take place which need not be described here. It is sufficient to say that in this process to which we have just referred, the *number of chromosomes is reduced to half of what they were in the original cells*. Consequently this process is known as *reduction division*. (Fig. 158.)

Chromosomes in Fertilization. In the section dealing with fertilization, it was pointed out that this process is essentially the same in plants and animals, and that it consists in the union of a sperm cell with an egg cell. The sperm cell, as has just been stated, contains half of the number of chromosomes found in the

body cells of the same species of plant or animal. The same is true of the egg cell. Consequently, when union occurs, the *fertilized egg will have the original number found in the body cells*. It is very significant, also, that *half of these chromosomes come from the male, and the other half from the female parent*. After fertilization, the fertilized egg divides in the usual way, and each resulting cell derives half of its chromatin from each parent. These facts are of high significance, when considered from the standpoint of heredity. (Fig. 159.)

Chromosomes and Heredity. Hereditary characters are those that are transmitted from parent to offspring through the germ cells. The extremely complicated behavior of the chromosomes in the processes just described, taken together with a large number of facts concerning the way in which characters are inherited, make it impossible to escape the conclusion that *the chromosomes are definitely concerned with the transmission of hereditary characters from parent to offspring*.

The behavior of chromosomes and their functions in the sex cells throws much light upon the facts of heredity as observed in plants and animals. In the section upon good seeds, the importance of selection in the field and the effect of pollen were discussed. It should be clear now why the parent that produces the pollen has just as much influence upon the hereditary character of the offspring as the plant that furnishes the egg and develops the seed.

Cells and Food Storage. Storage tissues, such as the cotyledons of the bean, the endosperm of corn, and potato tubers, are generally made up of thin-walled cells adapted for the storage of food. The substances most frequently stored are starch in the form of grains, and less often protein granules and oil droplets, and in a few cases, such as the beet, cane sugar dissolved in the cell sap. The protoplasm of these cells is active during the process of storage, and probably in most cases it remains alive until the food leaves the cells; although in some, such as the dry compact endosperm of corn, it is probable that the enzymes that digest the food originate wholly in the cells of the cotyledon.

Starch Storage. The interesting process of the formation of

starch grains in plants will serve to illustrate something of cell activity during food storage in general. In the potato, for example, the sugar is produced in the leaves and carried to the tubers. Here it reaches the starch plastids in the storage cells and is changed into starch through the activity of the protoplasm. This starch is deposited as a small granule. As more sugar comes to the plastids, layer after layer of starch is added to that already formed. Since these successive deposits vary somewhat in compactness, the grains when highly magnified show the concentric "rings of growth" characteristic of potato starch. (Fig. 21.)

The Cell as the Unit of Physiological Activity. The cell is not only the unit of structure of living things, but it is also the unit of activity as well. All of the functions and activities of the plant or animal body may be shown to be inseparably connected with the living cells. Consequently, to understand these processes — and they form much of the most important material of biology — one must have a clear idea of the cell and its structure.

The processes involved in the use of food in plants well illustrate why the cell is looked upon as the *unit of function*. In digestion, the enzymes that bring about the changes in the foods are always produced by the living protoplasm of the cells. After digestion, the food is taken into the various cells of the plant body where it is broken down in the process of respiration, utilized for growth purposes, or stored for future use. In any case, the living protoplasm of the cells controls the processes. Likewise, all physiological processes — even those of higher animals — may be shown to be connected inseparably with the activity of the protoplasm of the living cells.

DIFFUSION AND OSMOSIS

Examples and Definition of Diffusion. If a crystal of potassium permanganate, or other soluble substance that forms a colored solution, is placed in water, it may be observed that the solid gradually disappears, and that the liquid near the crystal indicates the presence of the compound. Likewise a substance such as ordinary perfume when exposed to quiet air becomes disseminated

to considerable distances, as indicated by the odor. It is said that even a metal like gold may gradually penetrate into another, such as lead, when they are held in close contact for a long time. This last, however, occurs with extreme slowness. The intermingling of the particles of a substance with those of another in contact with it and at rest, is known as *diffusion*.

Currents in Relation to Diffusion. The intermingling of the particles by diffusion is not due to currents in the liquid or gas that would mechanically carry the substance. Such movements greatly facilitate the intermingling of substances as is shown by stirring the sugar in the bottom of a cup of coffee, but this should not be confused with the process we are considering. *Diffusion will take place in the entire absence of currents of the water or air.* However, it is difficult to prevent currents of water or air from increasing the apparent effects of diffusion; for these substances are so mobile that a change in temperature or some slight mechanical disturbance is likely to cause movements that will carry the diffusing substances much more rapidly than when diffusion acts alone. Consequently, we rarely find cases where gases or liquids are involved, in which diffusion acts alone.

Apparent Cause of Diffusion. The scientist conceives the ultimate particles or molecules of all substances to be in constant and rapid vibration. This so-called molecular movement is least in solids and most vigorous in gases. That of liquids occupies an intermediate place between the other two. This vibration is increased by raising, and decreased by lowering, the temperature.



FIG. 53. — DIFFUSION

The fermentation tube contains water and a crystal of potassium permanganate. The distribution of the dissolved substance is, in part, a result of diffusion. (See text.) In the present case currents have carried some of the permanganate upward. The concentration of dissolved substance is indicated by the variation of color in the water—the darker is the more concentrated portion. (Original)

Example of Diffusion. When a soluble substance, as rock salt for example, is placed in water the vibrating molecules at the surface of the solid tend to fly off and mingle with the liquid, meanwhile maintaining their vigorous vibration. As a result the water in close proximity to the crystal comes to contain larger numbers of rapidly moving molecules than that farther away. As a consequence of this unequal distribution, a general movement of the molecules of salt at the beginning of solution takes place *away* from the crystal, or, what amounts to the same thing, *away* from the region of greatest concentration of salt molecules. This general movement continues until the distribution of salt is uniform throughout the water. It is very important to understand that in *the diffusion of a substance, the general movement of the molecules takes place away from the region of the greater concentration of the same kind of molecules.*

Osmosis Defined. *Osmosis is diffusion through a membrane.* If a piece of apparatus is arranged, as shown in Figure 54, with some suitable plant or animal membrane, as that from the interior of an eggshell, separating a glucose solution on the inside from faucet water on the outside, certain exchanges will take place that illustrate clearly what occurs in osmosis. Some of the sugar from the inside will pass through the membrane into the water, and, on the other hand, the volume of the solution in the tube will increase as a result of the entrance of water from the outside. The concentration of sugar is greater in the solution on the inside, at the beginning, than it is without, and by diffusion the sugar moves in the direction indicated, since the membrane used in this case does not prevent its passage.

The cause of the entrance of the water into the solution on the inside of the tube is not so easily explained, but becomes clear when one considers that a soluble substance, such as sugar, when dissolved, decreases the power of water to diffuse. A one per cent solution of sugar indicates that ninety-nine per cent of water is present, and a twenty per cent solution that there is eighty per cent of water. Thus water is the least concentrated in the stronger sugar solution. Diffusion of water then, as in the case of dissolved solids,

takes place *towards* the *least concentration of water molecules*. This process will continue until there is the same concentration of sugar as well as of water on each side of the membrane, and until equilibrium is thus established.

If table salt is in solution on one side of the membrane, and sugar on the other, the salt will diffuse into the sugar solution and increase in amount until the concentration of this substance is the same on both sides. Likewise, the sugar will pass through the membrane and become more abundant in the salt solution until equilibrium regarding this substance is established. The apparent movement of water will be determined by the relative concentrations of the two solutions. Thus, it should be clearly understood that *in osmosis, substances in solution pass through membranes independently of each other, and that they are, in no sense, carried by currents of water.*

The Character of Membranes. Membranes involved in osmosis vary

greatly in their character relative to the passage of different materials in solution. Some may allow several substances to pass

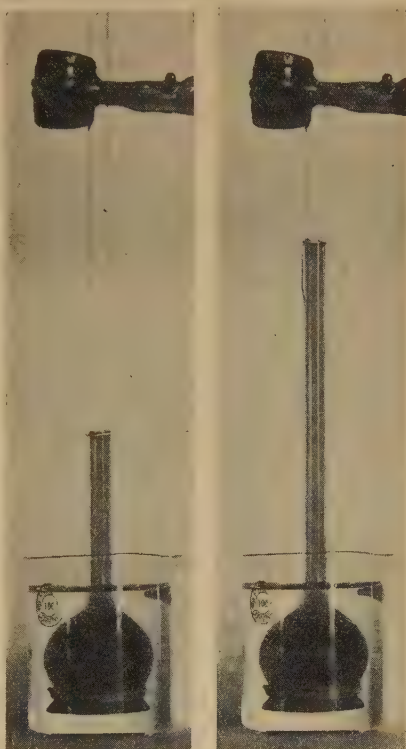


FIG. 54. — OSMOSIS

The glucose solution within the thistle tube is separated from the water in the beaker by a piece of the walls of a sheep's intestines.

Left — Apparatus just after being set up.

Right — Apparatus ten minutes later. The rise in the glucose solution is a result of the entrance of water from without. (Original photograph)

through with apparently equal facility, while others are very different and permit only certain ones to do so. A membrane that allows several substances to pass is said to be *permeable* for these materials; those that do not allow their passage are spoken of as *impermeable* to these substances; while other membranes that permit some to pass and not others, are said to be *semi-permeable*. Thus, the membrane from the inside of an eggshell is permeable to sugar and water, but impermeable to the albumen or the white of egg. If this membrane is considered in relation to a mixture of albumen and sugar, it is semi-permeable with reference to these substances, for it allows one to pass and not the other. The membranes of importance in plants, such as those concerned with the absorption of water by roots, are semi-permeable; the same may be said of those of the animal body.

Effect of Semi-permeable Membranes. Semi-permeable membranes in plants and animals modify in a remarkable way the results due to diffusion. Within the cells of plant roots, for example, we find sap that is more or less concentrated as a result of the solution of foods and various other substances. On the outside of the roots the soil water is very dilute; in fact, various substances found in the sap are not present there at all. Consequently, we might expect such materials as sugar to pass out of the roots into the soil, but, in general, such is not the case. The membranes found here are semi-permeable and prevent the escape of these valuable substances from the plant. At the same time, water from the soil and other substances pass into the roots and thus supply the plant with these necessary materials.

Turgor. The semi-permeable membranes of the plant cells are largely responsible for the condition known as *turgor* in cells, a term that refers to the stretched and rigid condition of these structures. Here the dissolved substances are prevented from diffusing out of the cells, and consequently, the water passes in until the cell wall is stretched. Moreover, this condition tends to be permanent so long as water is abundant; for the materials within cannot pass out and thus destroy the osmotic effects.

The condition may be illustrated in a striking way with a piece

of fresh red beet. If the slice is washed in cold water, the color which is held in the vacuoles of the cells by the membranes does not wash out and the piece of beet remains firm and rigid; but if heat is applied the color soon leaves the cells and diffuses into the water, and the firm, rigid character of the tissue disappears. The semi-permeable character of the membranes has been destroyed by the heat.

Plant and Animal Membranes. The membranes involved with the osmotic process in plants and animals consists primarily of living substance. This condition modifies greatly the process as it occurs in organisms. The protoplasm seems to have the power to change its permeability with reference to surrounding conditions, and thus it is able to govern to a considerable extent what materials may enter or leave the living cells. In the beet, just referred to, the permeability is altered by heat so that materials ordinarily held within the cells diffuse out readily. In this case the heat kills the protoplasm that is active in preventing the loss of the coloring matter and other substances from the cells. The living membrane doubtless may be influenced by various physical and chemical agents so as to bring about changes in its permeability.

On the whole, osmosis in the simple form, such as is used for demonstrations in elementary work, is seldom if ever found in plants and animals. In living things the process is apparently much modified, as for example in absorption in the intestines of animals.

Osmosis a Widespread Process. Osmosis is an important process not only with respect to living organisms, but also in the arts and in connection with many common practices in the home. In the chemical laboratory certain substances that do not diffuse readily through membranes are purified by means of *dialysis*, which is a special name for the process under discussion.

The salting of meat increases the concentration of the water outside the cells, and consequently that within diffuses out and thus the muscle becomes drier and harder. Likewise the cells or organisms that cause decomposition are acted upon and prevented from growing. This is largely on account of the lack of water within the

organisms. Doubtless the preservative power of salt is due chiefly to the osmotic results that it brings about when in solution. Strong solutions of sugar seem to act much in the same way in preserving fruits.

Effect of Rapid Removal of Water from Cells. In some cases, where the cells of fruits have a tendency to toughen, the water may be drawn out so rapidly that this may reduce the material to the hard leathery conditions sometimes found in preserved quinces or plums. Cucumber pickles sometimes shrivel from the same cause. Table salt or some other soluble compound may be sprinkled upon a walk to prevent weeds from growing. This effect of the salt is due probably to osmosis. The salt dissolves in the soil water and thus interferes with the absorption through the roots, and consequently, if plenty of salt is present, the plants wilt and die. Whether osmosis is the sole cause of all these results may be questioned, but certainly it plays an important part in them.

Osmosis in Plants. Osmosis plays an important rôle in every part of the living plant. The entrance of water and salts from the soil, the absorption of carbon dioxide from the air by the leaf, the passage of oxygen into the living cells during respiration, the transportation and storage of the food — in fact, all processes where substances enter or leave the living cells — involve osmosis in some form or other. For our purposes, it seems best to trace out, in some detail, one of the more important processes as it occurs in plants. This will serve as an illustration of what takes place in the others.

Osmosis and Root Hairs. In the section on root structure it was pointed out that the root hairs were important factors in the absorption of substances from the soil, and that they are outgrowths of the surface cells. The root hair is provided with a very thin cell wall. On the inside of this there is a delicate lining of living protoplasm surrounding a central cavity or vacuole containing water in which dissolved materials of various sorts are found. The living substance in the surface cells and in the hairs near the root tips makes up essentially the osmotic membrane that separates the soil

water and the soluble substances it contains from the sap within the ducts on the interior of the root.

Absorption of Water. The protoplasmic membranes of the root hairs are freely permeable to water, and the sap within has a higher concentration of dissolved substances than is the case with the soil water. Consequently, as has been pointed out, water passes into the interior of the cells and finally reaches the ducts through which it is carried to all parts of the plant.

Absorption of Dissolved Substances in the Soil Water. The absorption of other substances from the very minute quantities occurring in solution in the soil water is somewhat more complicated. Take, for example, certain necessary compounds containing nitrogen, known in general as nitrates. These are found in the soil water in very small amounts, so small, indeed, that it would seem impossible for the plant to obtain a sufficient supply from this source. The protoplasmic membranes of the roots are permeable to these substances which pass through into the interior, as we would expect; but here a new condition that is of great importance enters. *If the plant needs these substances, they are used up* more or less promptly and tend to disappear from the sap. Thus the concentration of the sap relative to these materials is held down to a very low point, and as a consequence, the materials constantly enter the plant from the dilute solutions in the soil. When there is no longer any use for them — that is, when they begin to accumulate in the sap — the passage inward ceases. Thus the plant is able to absorb the materials that it needs from the large number occurring in the soil water.

Osmosis in Animals. Osmosis may be just as important in animals as it is in plants, but it should be understood that the simple process seems to be much modified in these organisms. The absorption of food from the intestines in higher animals, as well as the entrance of sugar and other nutrients into the living tissues from the blood and lymph, doubtless involves diffusion and osmosis. Likewise, the absorption of oxygen from the air in the lungs and its entrance into the tissues preliminary to respiration, as well as the elimination of carbon dioxide and other wastes from the tissues,

are accounted for to some degree, at least, through these processes. In fishes and other gill-breathing forms, as well as with the one-celled animals found in stagnant water, much the same condition is true.

THE SOIL

The Importance of the Soil. The soil is one of the most important factors in the growth of the plant because it is here that the water and most of the other essential substances for growth are obtained. If these elements are not present in soil, or if they are in such a form that the plant cannot take in the supply that it needs for its growth, the soil is said to be *sterile*. On the other hand, if these substances are abundant and occur in a form suitable for the use of the plant, the soil is said to be *fertile*.

Variation in Soil. The land under cultivation varies greatly in its fertility, that is, in its power to produce crops. In some localities the clay hillsides from which the darker surface layers of the soil have been washed away and the uplands worn out by improper methods of tillage, and consequently rendered incapable of producing any sort of crop, are all too common; while not far away may generally be found bottom-lands or prairies of the richest soil,



FIG. 55.—SOIL STRUCTURE (Diagrammatic and highly magnified)

Note the variation in the size of the sand grains as represented. Also that each is surrounded by a thin film of water. See text for discussion. (Original)

dark in color and capable of giving heavy yields year after year. Between these two extremes there are many types of soil intermediate in character. The ability of the soil to produce plants depends upon many factors; but none is of more importance than the structure and composition of the soil itself.

Formation of Soil. Rock Particles. The fundamental basis of soils is decomposed rock together with sand particles of various

sizes. These substances have been formed through long periods of time by the breaking down and erosion of the rocks that at one time covered the surface of the earth. If one examines the débris at the base of a rocky cliff, he will see the immediate results of erosion somewhat as it occurred ages ago in the formation of the soil. The broken particles from the cliff vary much in size, hardness, color, composition, and in other ways, depending upon the kind of rock from which they originated. Likewise the constituents in the soil that accumulated as a result of decomposition and erosion of the original rock present a wide range of characters, and consequently the soils as a whole formed therefrom present marked differences.

Running Water and Soil Particles. Almost any small stream that is cutting its way down a slope will serve to bring out the character of the particles found in the soil. Running water has remarkable power to assort particles of suspended matter according to their sizes. The swift current will carry along all of the soil except, possibly, the very coarse gravel; but as the speed slackens, the coarser materials are dropped first and then, as the water flows more slowly, the finer sink to the bottom, and finally when a pool is reached, the minute clay particles are deposited. It should be added, however, that the finest clay may stay suspended almost indefinitely, thus rendering the water "muddy," as is the case with ponds in some localities. Thus the deposits formed by a small stream give a fairly accurate idea of the nature of the particles of soil through which it flows.

Organic Matter in the Soil. The term "organic matter," as used here, refers to substances of plant or animal origin, such as leaves, roots, and various other parts of plants and animals that become mixed with the upper layers of the soil and decay. These materials comprise a relatively small but very important part of all productive soils. Rock particles alone, no matter how fine they are, or how rich they may be in minerals essential for plant growth, are not capable of producing crops without the admixture of considerable organic matter. Even the very fertile sandy soils along our rivers soon become unable to produce abundantly if care is not

taken to keep up the supply of plant and animal remains that are likely to disappear so rapidly from this type of soil. Likewise the upland, that has lost its organic matter through prolonged cultivation and improper methods, remains practically sterile until a new supply of organic matter is added.

Addition of Organic Matter to Soil. Very early in the period of soil formation, simple organisms—probably one-celled plants—gradually appeared upon the surface and left their remains in the soil. This made a more abundant growth possible. This process continued for long periods of time, and thus the decomposed rock was transformed gradually into a soil capable of producing a growth of plants such as we are accustomed to see upon our fertile prairies or in the rich bottoms. Organic matter tends to disappear through decay and through the action of various atmospheric agencies. However, the myriads of plants and animals that now live in and upon the soil die and their remains, if not removed, serve to maintain this supply.

Distribution of Organic Matter in the Soil. The supply of organic matter is found chiefly in the surface layers of the soil. This is generally indicated by the darker color of this portion as compared with the lighter shades deeper down. When the plant structures, such as leaves for example, decay, the resulting substance is generally dark in color, like the leaf mold that is common at the surface of the soil in deep, damp woods. When organic matter is abundant in the soil, its presence is generally easily determined by the color. It should be understood, however, that blackness in soil is not a certain indication of the presence of this valuable material in a form suitable for plants, for sometimes very dark shades are due to other causes.

The remains of plants, such as leaves, stems, and branches, as well as the bodies of many animals, are most likely to be upon, or very near, the surface of the soil. Some roots and certain animals penetrate the soil to considerable depths, but the organic material from these sources is but small in amount compared with the other supply.

Bacteria and Related Organisms in the Soil. Bacteria and

certain other low forms of life play such an important part in the fertility of the soil that it seems necessary to call attention to them here.

1. Many of these forms are very closely concerned with the changes of the organic matter in the soil whereby this material is converted into substances suitable for the use of green plants. In fact, plant and animal remains, without the presence of bacteria and related organisms, would be useless for the nourishment of the growing plant.

2. These organisms also have another important function in relation to the fertility of the soil. As they grow in the soil, substances are produced, such as carbon dioxide, that act upon the otherwise insoluble rock particles and bring about such changes in the minerals present that the plant is enabled to take in and utilize certain compounds that it must have for growth.

3. There are other bacteria than those referred to above that are very important in connection with the enrichment of the soil through the use of clover and other legumes. With these forms rests the power to take the nitrogen from the air and to convert it into compounds that make it possible for the green plant to obtain a sufficient supply of this important element, so frequently lacking in ordinary soils.

Texture of the Soil. The term texture or structure refers to the physical characters of the soil, whether it is coarse or fine grained, mellow or compact, easily pulverized or hard and cloddy, and the like. These qualities are determined largely by the size, arrangement, and character of the particles that make up the bulk of the soil. The presence of organic matter and certain other materials, such as lime, sometimes influences the texture to a marked degree, as is shown by the physical improvement of worn-out soils through the addition of these substances.

Texture of Soil in Relation to Plant Growth. The conditions to which we have just called attention are of great importance when considered from the standpoint of the development of the plant. A soil that gets very sticky and plastic if worked when it is a little too wet, and as a result forms a hard, compact mass when

it dries out, must be handled with care if a good crop is to be obtained. On the other hand a soil that is coarse grained, and thus drains well, and does not become compact, even in wet weather, is very easy to manage and furnishes an excellent bed for the development of the roots of young plants. It should be said, however, that probably the most satisfactory soils we have belong to neither of the groups suggested above, but possess qualities of an intermediate nature, such as do the rich brown silt loams of the prairies of the Middle West.

Groups of Soil Particles. Soil particles vary in size from those found in the coarsest sand or gravel down to those so minute that the highest powers of the microscope are required in order to see them at all. Below these we find that much of the soil substance has been broken down into plastic materials that have entirely lost their granular nature, such as those which give the characteristic qualities to the finest grades of clay. There is no break in the series of particles until we get to the plastic substances; nevertheless, it is convenient to group these materials originating from rock into three classes, as follows:

1. Omitting rocks and gravel from our consideration, the coarser particles in the soil are included under *sand*. Sands are spoken of as coarse, medium, or fine, depending upon the size of the grains. Although the finer particles are difficult to see, yet all may be said to be in the range of vision of the unaided eye. 2. *Silt* includes a grade of particles more minute than the fine sand. These do not feel gritty to the touch, yet the microscope shows them to be granular also. 3. *Clay* refers to those materials still more minute than silt particles, and differs from the others in lacking granular structure and in possessing remarkable plasticity such as is found in the potters' clay.

Effect of Size of Particles upon Soil. All of our ordinary soils are mixtures of these three classes of particles, together with varying quantities of organic matter. Their physical qualities vary according to the relative amounts of each constituent present. Thus, if *sand* is relatively abundant, it imparts the characteristic qualities such as appear in certain soils of our bottom lands, which

are always loose and easily worked. Generally speaking, if a large amount of *clay* is present, and unless care is used in the methods of tillage, the soil is characterized by extreme plasticity when wet, and by hard, resistant clods when dry. Soil of this type, however, when it contains a high percentage of organic matter which modifies its physical character to a marked degree, forms some of the most fertile lands to be found.

The intermediate group of soils known commonly as *silt loams* contain relatively large quantities of *silt* mixed with the other materials. The term *loam* refers simply to a mixture of all of the soil constituents with no one predominating. A large proportion of the land under cultivation is of the silt loam type and contains varying amounts of organic matter which causes the color to range from dark brown to light gray. If there is sufficient organic matter present, these soils are generally easily worked and form excellent beds for the growth of plant roots. Brown silt loam is the most typical soil of the North Central States, an area which leads in the production of corn and other crops.

Water in the Soil. The relation of water to the soil and, consequently, to the growing root is a subject of great importance in connection with the development of the plant. 1. All of the water used by the plant, whether in the tissues themselves or evaporated from the leaves, is obtained from the soil. Not only this, but the supply of necessary mineral compounds used by the plant is obtained from the soil water in which these substances are dissolved before they are absorbed by the plant. 2. Water is also very important in connection with the physical condition of the soil. This, we have seen, is a very influential factor in the development of the plant. For example, a soil that is poorly drained, or that holds large amounts of water because of its structural characteristics, is slow in warming up in the spring, and even when dried out, it is likely to be in poor physical condition.

Soil Water. The water that is available for the use of the plant occurs largely in very thin films that surround the particles of the soil. This relation is shown clearly in the diagram, Figure 57. The films of adjacent particles are joined together forming con-

tinuous but very irregular layers of water extending through the moist soil. The water held in this way upon the surfaces of soil particles is commonly known as *capillary* water.

If water is very abundant in the soil, it may fill the larger spaces between the coarse particles: since this drains out readily as a result of the force of gravity, it is known as *gravitational* water. This portion of the soil water is not only of little value to the plant but even causes injury to the roots, probably through the exclusion of the air from the soil. When the soil is dusty and apparently

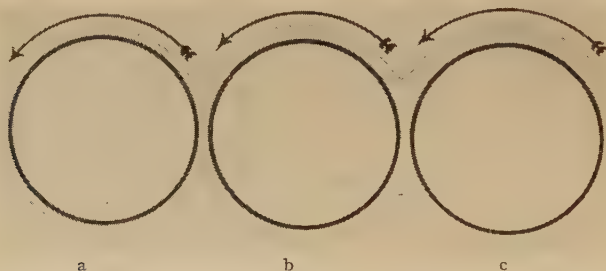


FIG. 56.—DIAGRAM INDICATING THE NATURE OF THE MOVEMENT OF THE WATER HELD IN THE FILMS SURROUNDING THE SOIL PARTICLES

The circles represent soil particles that are in contact. The films of water about the circles are continuous. The arrows indicate the movement of water when a film, as at the left, becomes thinner as a result of absorption by roots or from some other cause. See text for discussion. (Original drawing)

dry, as we often see it during hot weather in the summer, still some water is present; but this is held so firmly to the particles that it can be removed only by special means such as the application of high temperatures. Consequently this water is of no value to the plant, for the roots are unable to take it from the soil. The presence of organic matter increases the capacity of the soil for holding water.

Movement of Water in the Soil. The diagram (Fig. 56) represents three adjacent spheres covered with continuous water films. The thickness of the films tends to remain equal at all places unless there is some disturbing influence. If for any reason the thickness of any film decreases, as of *a* for example, a move-

ment of water from *b* and *c* takes place until equilibrium is again established. The same movement takes place in moist soil where the particles are compact enough to cause the films to be continuous. A loss of water from one portion tends to be balanced by transfer from more or less distant parts where the films are thicker.

Advantage of the Water Movement to the Plant. When the absorbing portion of a root takes in water, the films of the nearby particles become thinner, and consequently a movement sets in from a distance towards the place where the water is entering the plant. This general transfer of water is shown in a diagrammatic way in Figure 57. The water that moves as just indicated contains dissolved substances, some of which are essential for plant growth. Thus the growing plant may draw, not only upon water, but upon other essential materials that may be found at considerable distances from the root hairs.

Use of Compact Soil in Dry Weather. It sometimes happens, especially in dry weather, that the soil is too loose, or a layer of coarse or-



FIG. 57. — DIAGRAM REPRESENTING THE MOVEMENT OF WATER IN THE SOIL TOWARD AND INTO A ROOT HAIR

1. Tip of root hair. 2. Air spaces. 3. Soil particles, each surrounded by a film of water. Arrows indicate the direction of movement of the water. See text. (Original)

ganic matter, such as straw, interferes with the upward movement of water from the deeper layers of soil. In such cases, rolling the land or pressing down the loose soil over the seeds in some other way is of advantage in aiding the water movement. This treatment, which compresses the dry, loose soil, tends to bring the particles into intimate contact and thus aids in bringing about continuity in the water films that have become broken. That this compressing of the soil is of advantage to germinating seeds and to the young seedlings is often observed in the garden in dry weather,

where the young plants frequently come up in the footprints of the gardener, or in other compact places, sooner than in the loose soil nearby.

The Granulation of Soil. When a compact, fine-grained soil, such as ordinary clay, for example, becomes wet and dries out again and again, or when it freezes and thaws several times, as frequently occurs in our winters, the minute particles gradually collect into aggregations known as *granules*. Such a soil is said to be granulated. This is well illustrated in Figure 58. These large

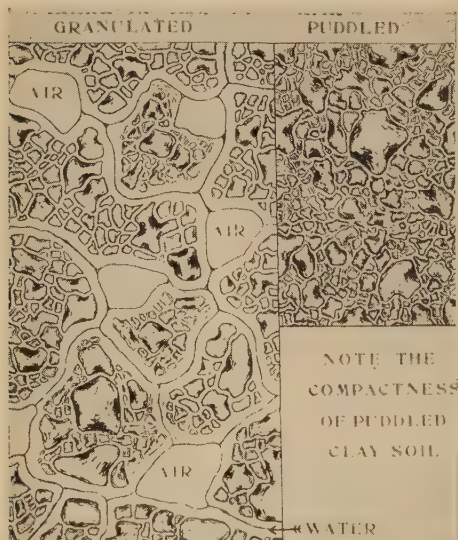


FIG. 58. — DIAGRAM ILLUSTRATING THE STRUCTURE OF GRANULATED AND PUDDLED SOILS

Note especially the air content and the arrangement of particles in the two soils. (From a wall chart by the author)

composite particles behave much like the coarse grains in a sandy soil, and thus modify the physical nature of the fine-grained soil to a marked degree.

Puddling of Soil. In a wet soil the large granules apparently are surrounded by comparatively thick films of water, as is shown in Figure 58. Any disturbance of the soil while it is in this condition is likely to break up the granules and thus cause the fine particles to become firmly united into a dense mass which exhibits a marked plasticity. This is essentially

what occurs when clay is worked thoroughly before it is molded into the forms of tile or pottery in the manufacture of these products. Soils, when in this condition, are said to be *puddled*.

Puddled Soil and Plant Growth. Upon drying, puddled soils frequently form very hard, compact masses that may remain re-

sistant for an indefinite time and thus interfere in a marked degree with the growth of roots and, consequently, with the development of plants. It follows from this that any treatment that may result in the breaking up of the granules of a soil, such as plowing when too wet, or allowing stock to tramp over a muddy field in the spring, is very unwise from the standpoint of plant production. Soils treated in this way frequently show, throughout the growing season, the injurious results of such a practice.

If a well-granulated soil is allowed to dry sufficiently before it is worked, the granules will retain their structure and a mellow condition will result. This is well shown by the ease with which suitable seed beds are prepared in a dry spring that follows a winter in which there has been good weather conditions to bring about a thorough granulation of the soil.

The Influence of Certain Substances upon Granulation. The presence of organic matter, or of certain other substances, such as some lime compounds, have marked effects in promoting the granulation of the soil. Certain other complex substances, found in some soils that have been cultivated for many years, seem to prevent the formation of granules, even when the physical conditions are suitable for granulation to occur. These facts explain why some soils remain in superior physical condition while others nearby do not.

Air in the Soil. Air penetrates into the soil to considerable depths. This is important in relation to the development of plants. The importance of this process in living, actively growing tissues was pointed out in the section upon respiration. The portion of the root chiefly concerned with the absorption of water and other essential substances is the rapidly growing region near the tip. In fact, the root hairs, through which practically all these substances enter the plant, are often short-lived and, consequently, must be replaced by others that are added continually very near the tip. The growth of these structures is essential for the proper functioning of the roots. The oxygen found in the soil air is the source of this element that makes possible respiration as it occurs in these actively growing regions. Without the supply of air, this essential

process underlying growth must cease; consequently, the formation of active new tissues is rendered difficult or impossible.

Effect of Draining of Soils. If the soil becomes water-logged, that is, if water fills all the spaces usually occupied by air, and thus surrounds the roots with a new set of conditions, the effect upon the growing crop is disastrous. This is illustrated when growing corn, for example, is injured by water standing upon the soil. Probably some of the most beneficial results following the tilling of land and the improvement by surface drainage are concerned with the better aeration of these soils.

CHAPTER VI

STEMS AND LEAVES

STEMS

Types of Stems. The portion of the plant between the roots and the leaves, broadly speaking, is referred to as the *stem*. It will be seen at once that this part in different plants varies greatly in form and in other ways as well. Some stems are short, as in the dandelion, the leaves of which seem to be attached directly to the roots; while others are of great length, towering a hundred feet or more, as is often the case with our forest trees. Some are hollow and soft, as with many grasses; while others are solid and very resistant, as in the woody plants.

Functions of the Stem.

Stems have three functions that appear with considerable regularity in the various types of plants. 1. Probably the most characteristic function is the distribution of water and other substances to the various parts of the plant. In plants where the

roots and leaves are separated by considerable distances this is very important; but in others where the leaves arise very near to the roots this function is not so marked. 2. Many stems serve



FIG. 59. — DRAWING MADE FROM A SPROUTING IRISH POTATO SHOWING THE DEVELOPMENT OF THE BUDS (eyes) INTO SHOOTS, AND ALSO THE FORMATION OF THE ROOTS (Original)

to hold the leaves up in the air and sunlight. This is strikingly true of those that are of large size and have well-defined, rigid stems, such as trees, shrubs, and many agricultural plants. In

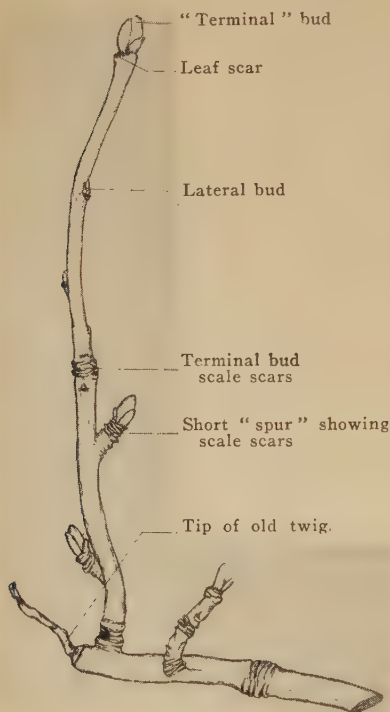


FIG. 60. — EXTERNAL STRUCTURE OF AN APPLE TWIG IN WINTER CONDITION

Note the effect of the dying of the tip of the old twig which resulted in the development of the lateral buds. (Original)

for with these no functional leaves occur. In many young stems of woody plants as well as of herbs, the process also takes place to a limited extent but in such cases it is of comparatively slight importance.

a considerable number of forms that lie close to the ground, or that float in the water, this function is apparently of less importance. 3. Stems of plants frequently serve for food storage. With the perennials, such as trees and shrubs, this is of the highest importance; for the food that is to enable the plant to put out leaves in the spring is generally stored during the winter in considerable amounts in the permanent tissues of the stem. In the cases of the annuals and many biennials the stem can be, at most, only a temporary place of storage, for with such plants the stems generally die at the approach of winter.

A minor function of stems that may be mentioned in passing is photosynthesis. In some plants, as garden asparagus and a large number of desert species of the cactus type, the production of food in the stem is of great importance,

External Structures of the Woody Stem. An apple branch as large as a lead pencil provides excellent material for the study of the external features of the typical stem. In the summer and early autumn, the portion formed during the earlier part of the year bears *leaves* that appear on the stem at certain definite points called *nodes*.

In the angles formed by the leaves and the stem, known as the *axils*, *buds* are usually present. The buds that are located on the sides of the stem are spoken of as *lateral buds*. Those at the tips of the branches are called *terminal buds*. When the leaves fall at the approach of winter, a scar, which is just below each lateral bud, and which is known as a *leaf scar*, is formed. This scar remains rather clearly defined for a year or more.

A brief study of a terminal bud shows that it is covered by a series of several overlapping scales which are attached to the tip of the stem. When the bud develops and the scales drop off, a circular scar remains that reaches entirely around the stem at this point. This *terminal bud scale scar*, as it is called, remains visible for several years as the stem increases in length. Since the terminal bud marks the end of a year's growth, it is often an easy matter to estimate the age of a young branch by counting the number of terminal bud scale scars.

Structure of Buds. The structure may be easily made out if

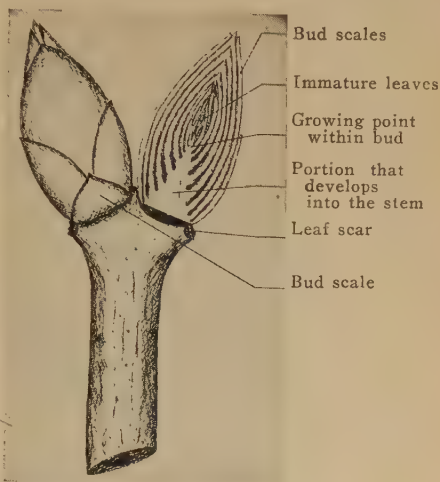


FIG. 61. — STRUCTURE OF A LILAC BUD

Left — External view.
Right — Bud cut longitudinally through the center showing the interior structures. (Original)

a large bud, such as one from the lilac, is dissected or is cut open through the center, as shown in Figure 61. A series of scales forms the outer portions and near the center tiny, immature leaves appear. These small leaf-like structures are attached to a central axis that arises from the stem and extends through the bud. The tip of this



FIG. 62.—STRUCTURE OF A MOUNTAIN ASH BUD WHICH CONTAINS AN IMMATURE FLOWER CLUSTER (Winter condition)

Left — Exterior view. Right — Interior view through the center. (Original)

central portion is soft, and since it is made up of actively growing cells, is known as the *growing point*. The tip of each growing branch has a similar growing point. If in any way the growing point in a terminal bud is destroyed, those within the lateral buds near by develop more rapidly and take the lead. (Fig. 72.)

Growth of Buds. When a bud renews its growth in the spring, the central axis lengthens out, the young leaves enlarge, and finally it forms the shoot with its stem and leaves. Essentially, then, a *bud is an undeveloped shoot*. In buds that are

to give rise to blossoms, the immature flowers instead of the rudiments of the leaves may often be found in the center. (Fig. 64.)

Elongation of Shoots. With most common plants, grasses excepted, increase in length of shoots takes place near the tips. With these, the growing points generally consist of groups of cells that are capable of active division. These cells are situated at the tips and are very similar to those occurring in the root tips of the onion, which were discussed on page 82. The cells produced in these growing points elongate rapidly and soon become transformed into the various tissues of the stem. With some plants, notably certain vines, this growth takes place very rapidly, and the increase in length may, under favorable conditions, be as much as several

inches in twenty-four hours. It will be recalled that in the grasses, the stems elongate as a result of growth at several points, namely, just above the nodes in which regions the cells retain their power of division during much of the active growing period of the plants.

Comparison of Stems and Roots. Generally it is not difficult to distinguish stems from roots. Ordinarily, stems are in the air while roots are in the soil. When, as sometimes happens, the



FIG. 63.—DEVELOPMENT OF THE LILAC BUD SHOWING SUCCESSIVE STAGES IN THE GROWTH OF THE SHOOT (Original photograph)

conditions are reversed, certain structural differences serve to distinguish the two. 1. Stems have nodes from which leaves and branches arise, while roots have no such regions. Consequently, branch roots are irregular in their distribution. 2. Stems generally have leaves, or at least, scale-like structures that correspond to leaves. Roots have nothing similar to these. 3. Branches of the roots originate beneath the surface of the plant body as is well shown in a section of a parsnip, while branches of the stem arise

at, or very near, the surface. There are also certain differences in the internal structures of the two.

Underground Stems. Underground stems are those that grow beneath the surface of the soil. Some very pernicious weeds, as the quitch, or quack grass, are propagated largely through these structures. (Fig. 65.) In fact, many weeds owe much of their tenacious character to underground stems, or to long roots that serve the same purpose. The Irish potato is a remarkable example of an underground stem that is specialized for food storage and



FIG. 64. — DEVELOPMENT OF THE "FLOWER" BUD OF MOUNTAIN ASH
(Original photograph)

propagation. The eyes on the tuber are buds, and, in the very young stages, small scales that represent leaves may be seen.

Internal Structures of a Dicotyledonous Stem. A dicotyledonous stem is a rather complicated structure. It is made up of a number of well-defined tissues, as one may see by referring to Figure 66. Only a few of the more important parts need be mentioned here. The figure mentioned was constructed primarily to show what takes place in the woody stem as it develops

from the first year condition through several succeeding seasons. The diagrams should be studied with care in connection with the description.

Diagram A represents a cross section of a one-year-old woody vine, known as Dutchman's Pipe. Several well-defined regions are present. These are as follows. 1. The central part, or *pith*, is composed of thin-walled cells which are of considerable importance from the standpoint of storage. 2. Situated around this central region is a circle of oval structures, representing in cross section strands of tissue known as *fibrovascular bundles*. 3. Between these bundles are narrow portions of tissue similar to that in the pith region and which finally give rise to the *primary medullary rays*.



FIG. 65.— UNDERGROUND STEM OF QUACK GRASS SHOWING METHOD OF PROPAGATION (Original)

4. Outside of the circle of fibrovascular bundles are several tissues that go to make up the outer layers of the "bark" of the young stem. 5. Finally at the surface there is a single layer of cells forming the *epidermis*, the outside walls of which are covered with a waxy layer known as the *cuticle*. The last-named structures protect the tender cells beneath from mechanical injury and the loss of water as well as in other ways.

Fibrovascular Bundles. The fibrovascular tissues are very important structures of the stem. These bundles arise near the grow-

ing tip and consist of long, slender, fibrous strands that extend lengthwise through the stem and are continuous with similar structures in the roots. A fibrovascular bundle as found in the Dutchman's-Pipe vine is made up of three definite parts. The inner portion consists of a number of large tubes, called *ducts*, that are

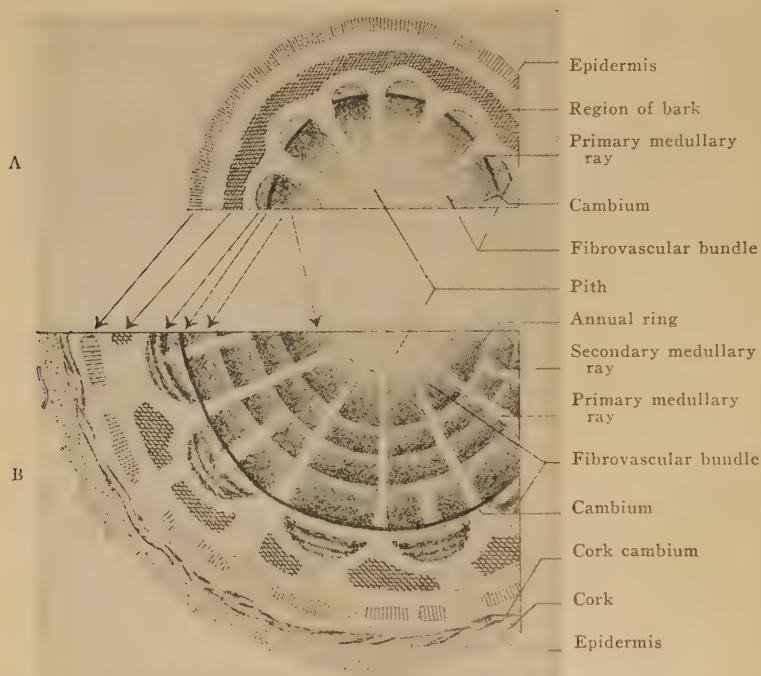


FIG. 66.—CROSS SECTIONS OF A WOODY STEM (*Aristolochia*)
(Somewhat diagrammatic)

Above—One-year-old section. *Below*—Four-year-old section.
See text for full discussion. (Original)

held firmly together by thick-walled woody cells. This portion of the bundle is known as the *xylem*. *The water absorbed by the roots is carried upward through the xylem and distributed throughout the plant.*

On the outside of the bundle is a region known as the *phloem*, composed of tubes also; but here they are much smaller and contain peculiar sieve-like structures, and hence are called *sieve tubes*. *It is through the phloem that the enriched sap containing various dissolved food substances is carried*. Between the xylem and phloem there is a layer of thin-walled cells that, when seen in a highly magnified cross section, remind one of bricks in a wall. This is the *cambium*. This tissue retains the power of division indefinitely, and during the growing season, *continually forms new cells*. On the one side these are added to the xylem, and on the other to the phloem. The cells thus produced soon become transformed into the specialized structures of these regions.

This addition of material enlarges the fibrovascular bundles, which approach each other and finally are separated only by the thin medullary rays. Thus the circle of bundles at last becomes united into a solid woody cylinder about which the cambium exists as a continuous layer of cells capable of active division. This is about the stage of development in which the stem generally passes the first winter.

Annual Rings. When the plant becomes active the following spring the cambium adds new tissue to the already existing xylem. The ducts formed in the early part of the growing season are larger than those produced later, and, consequently, the tissue added at this time is often very porous. As the growing season passes, the ducts formed become smaller, and a larger proportion of solid woody tissue is produced; hence the late growth, known as the *summer growth*, is in many trees much more compact than the tissues formed in the spring. This gives rise to a ring which shows clearly in cross section, and which is known as an *annual ring*, so called because one is generally formed each year. After the formation of the compact summer wood, the cambium again rests over winter and renews its activity the following spring.

New tissue is also added to the phloem by the cambium, but the older layers become compressed by those newly formed; consequently the annual additions are not so clearly defined here as in the xylem region of the stem. From the cambium also originate,

from time to time, additional medullary rays, known as *secondary rays*. Some of these are represented in Figure 66, *B*.

Cause of Rough Bark. Year after year the cambium adds new rings of xylem to the woody cylinder within, thereby increasing its diameter. Likewise it adds new layers of active phloem to the tissues outside the cambium, commonly called the *bark*. Since the woody cylinder continually becomes larger from the addition of new annual rings from the cambium, the original tissues in the bark of the young stem soon become too small. Consequently, these tissues break into segments and new cells are inserted between the parts, as shown in Figure 66, *B*. The changes just described give rise eventually to the rough external bark of many of our forest trees.

Cork Formation. While the growth described above is taking place, just beneath the epidermis certain cells, known as the *cork cambium*, become active. These cells divide rapidly and produce the *cork*, a tissue that occurs abundantly near the surface of many woody stems, and serves as a protection from water loss. As new cells are added to the bark on the interior by the cambiums, the outside layers, consisting of cork and other tissues, gradually fall off. Generally the bark sheds nearly as rapidly as it is added to from beneath; consequently, it does not increase in thickness very rapidly. These typical tissues of a four-year-old stem of Dutchman's Pipe vine are shown in cross section, in Figure 66, *B*.

Structure of Oak Wood. Oak offers excellent material for the study of wood structure in that it shows the more important tissues clearly; moreover, it is used often for furniture and interior finishing of houses, matters in which most people are interested. A careful study of Figure 67 will serve to bring out clearly the more important characteristics of the wood. Of these the annual rings and the medullary rays are of great interest, for they are the structures that give to oak the beautiful and characteristic grain.

Sap Wood. Heart Wood. The annual rings next to the bark are lighter in color and somewhat softer than those towards the heart of the tree. This region is made up, to some extent, at least, of living cells. Through ducts in this portion of the stem

the sap is conveyed upward from the roots. It is, therefore, called the *sap wood*. After a few years, as new layers of sap wood are added by the cambium, those nearer the center of the stem cease to function in carrying the sap, and become a part of the interior

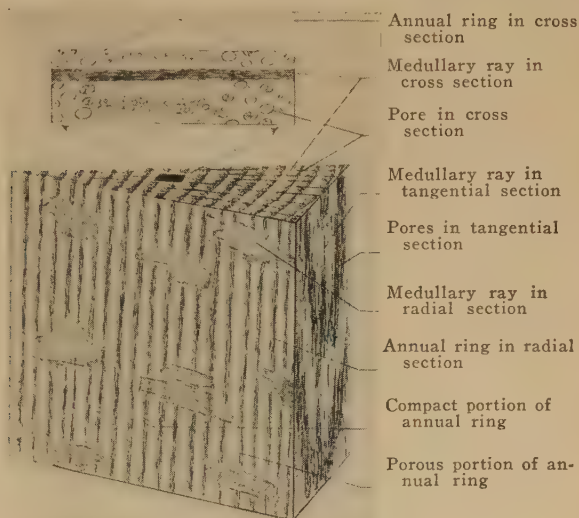


FIG. 67.—A BLOCK OF OAK WOOD
SHOWING THE THREE SECTIONS

Upper figure — A portion of the cross section including an annual ring magnified.

Lower figure — Block about natural size. The heart wood is at the left; the sap wood at the right. (Original)

heart wood. This portion of the stem is generally darker in color as a result of the accumulation of certain oils or other waste substances of the plant, and often becomes very hard and durable. The heart wood is generally the most valuable portion for lumber.

Wood Sections. The direction in which the log is cut in sawing the lumber, determines very largely the appearance of the wood and consequently its value for furniture and other similar uses. The three sections shown in the cut should be clearly understood by the

student. The *cross section* passes directly through the log at right angles to its length; the *radial* is a lengthwise section that passes through the center of the log; and the *tangential* is a longitudinal section cut from the side of the log, and consequently at right angles to some of the medullary rays. The most prized is the radial section which in oak shows the rays as glistening plates beautifully distributed over the surface. Lumber cut in this way is said to be *quarter-sawed*.

Quarter-sawed Oak. Quartered oak is highly prized for furniture, but in its production there is much waste; consequently, it is higher priced than oak sawed in the ordinary manner. Sometimes the log is quartered, and then cuts are made parallel to the smooth faces, giving a few boards that are quarter-sawed. Other methods may also be used, but always there is waste and extra expense attached to the production of this type of lumber.

Veneers. Very thin sheets of wood which have beautiful grain often are firmly glued to other pieces of lower priced lumber; thus veneers are produced. This method is used very largely at present in the manufacture of furniture, doors, panels, and various other articles where beauty of grain is desired. The veneer is advantageous in that it is much cheaper, and at the same time often stronger than the solid piece.

Advantages of Veneered Furniture. Some woods that take a beautiful finish, such as sweet gum and mahogany, are not strong, and so these are made into thin sheets that are glued to birch, or another tough, hard type, giving a finished product much more durable than it would otherwise be. Veneered furniture is frequently much more beautiful than would be possible otherwise, for by this method wood of suitable grain may be joined together in ways to give the most striking results, such as are often produced in piano cases and expensive tables. Another advantage of the veneer is the possibility of reducing the weight of large pieces of furniture. A solid oak table, for example, is very heavy, but one made of veneer may be much lighter and still be just as satisfactory in other ways.

The Monocotyledonous Stem. *Interior structure.* The stem of a monocotyledonous plant is very different in structure from the type just studied. In the cornstalk, for example, the outer portion is very hard and compact, and the interior is filled with a soft pith through which the fibrovascular bundles pass. (Fig. 68.) These bundles are essentially similar to those of the dicotyledonous stem, in that they contain xylem and phloem, regions which function

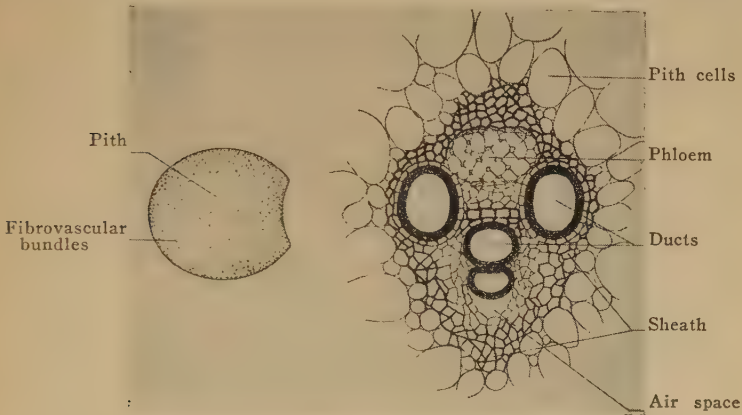


FIG. 68. — STRUCTURE OF A CORN STALK

Left — Cross section about natural size.

Right — A single fibrovascular bundle highly magnified. (Original)

as in the other plants. They differ, however, in not having a permanent cambium. In fact, the stalk does not enlarge by additions from a cambium as is the case with the plants just studied.

Exterior structure. The nodes of a monocotyledonous stem are generally much more marked than is the case with those of the dicotyledons. Monocotyledonous stems are generally hollow or filled with pith, and consequently, there is danger of their collapsing, a condition which is prevented by the more solid portions at the nodes. The arrangement of the materials in many types of monocotyledonous stems is, from the mechanical standpoint, most excel-

lent for rigidity and strength combined with a minimum of material. (Page 14.)

Healing of Wounds on Trees. A wound on a tree caused by the removal of a branch, or in some other way, generally will heal

readily if conditions are favorable. This healing process is interesting. Take, for example, the wound caused in the removal of a branch by sawing close up against the body of the tree. The cambium that is exposed around the edge of the wound becomes very active during the growing season and produces at first a temporary tissue; finally wood and other permanent structures are formed that gradually close over the wound from all sides. (Fig. 69.) Under advantageous conditions this growth will continue until the wound is entirely covered. (Fig. 73.)

Danger of Open Wounds in Trees. Wounds that do not heal quickly are of common occurrence and often result in the destruction of the tree. Such injuries allow certain low forms of plants, known as fungi, to enter and grow upon the tissues of the stem, finally producing decay that totally destroys the wood and sooner or later ruins

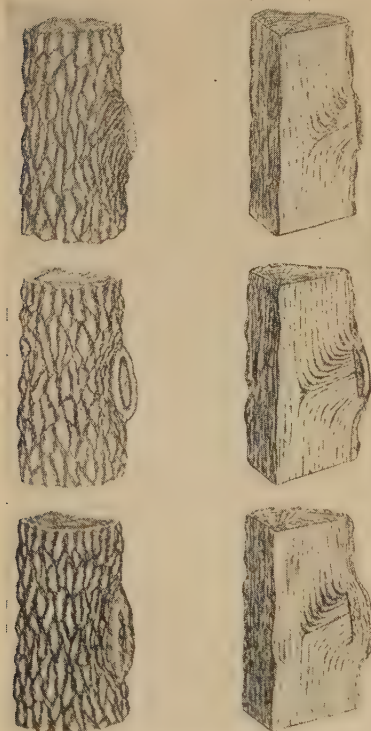


FIG. 69.—THE HEALING OF A WOUND WHEN THE BRANCH HAS BEEN PROPERLY REMOVED

Left — Exterior view of a portion of the trunk. *Right* — Interior view of the same. (Original)

the tree for timber or decorative purposes. The hollow and diseased trees of almost any woodland will afford abundant evidence as to the importance of the care of wounds.

Pruning of Trees. Since the healing growth originates in the cambium of the living stem, it is absolutely necessary in the removal of branches to cut them off close to the body of the tree. Otherwise, a stub will remain that will die, making it impossible for healing to take place, and finally a knot-hole will result that remains a permanent menace to the life of the tree. (Fig. 70.) All broken branches and snags should likewise be removed. (Fig. 72.)

Tree Surgery. Sometimes cavities in valuable trees are treated much in the same way that teeth are filled by the dentist. This doctoring of a tree is known in general as *tree surgery*. Just as the dentist cleans out the cavity in the tooth with care, so the tree surgeon cuts away the dead and diseased wood. When the cavity is thus prepared, the interior is sometimes washed with a substance that is deadly to any fungus or other organism present. A filling, generally of cement, is then placed in the cavity in such a way as to exclude the water. When the work is properly done the wood grows over the cement surface so that frequently the filling becomes entirely covered. (Fig. 74.)

Budding and Grafting. In the process known as *budding*, a bud, generally from a tree that it is desirable to propagate, is removed and inserted into the growing tissues of a nearly related plant known as the *stock*. When properly done this bud will

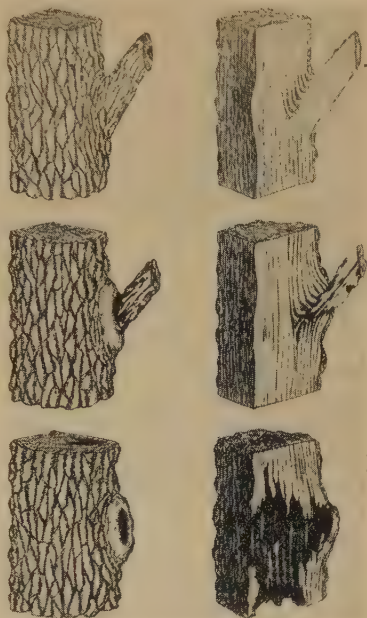


FIG. 70. — INJURY RESULTING WHEN A BRANCH HAS BEEN CUT OFF LEAVING A STUB

Left — Exterior view. Right — Interior view. (Original)

develop, producing in time a plant similar to the one from which it came. *Grafting* is essentially the same except that an entire shoot, called a *scion*, is used instead of a single bud. The fundamental step in the process is to bring the cambium of the bud or scion, as the case may be, into close contact with that of the stock. Under conditions suitable for rapid growth the two portions, thus

brought together, readily unite, and soon the wound may be entirely healed. Sometimes wax is used to cover the wound for protection. (Fig. 75.)

Importance of the Grafting and Budding. It is impracticable or even impossible to reproduce many of our cultivated plants, such as the orchard fruits, from seeds. As is generally known, if the seeds of the Winesap apple, for example, were planted there would be virtually no chance of the young trees thus grown

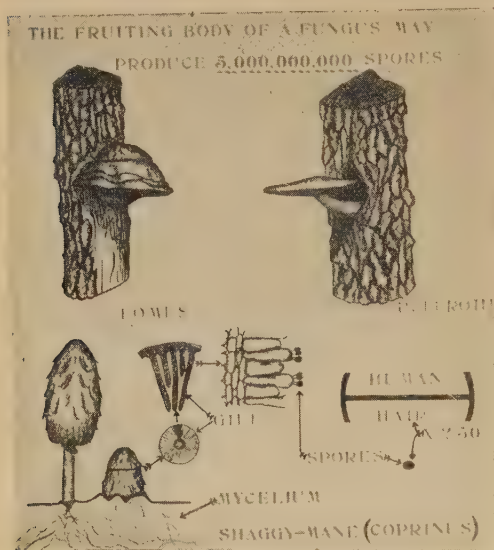


FIG. 71. — THE NATURE OF FUNGI

Above — Types that grow upon trees. *Below* — A common form that grows upon the soil. See text under *Fungi* for discussion. (From a wall chart by the author)

producing apples of this type. In fact, if enough seeds were planted there would be innumerable types, the vast majority of which would prove worthless. Moreover, the time required for such plants to come to bearing is so long, that it would be out of the question to develop seeds that would come true to type by a process of selection, such as is practiced with many of our annual plants. (Chapter XI.)

By budding or grafting, however, this difficulty is overcome and

a plant of excellent quality may be multiplied almost indefinitely and with great rapidity. Often plants with very vigorous root systems are used as stocks, and thus the general vigor of the tree is increased. The importance of these methods will be apparent when it is known that a large portion of our perennial cultivated plants are multiplied by these or other related processes.



FIG. 72. — THE EFFECT OF PRUNING UPON BRANCHING

Note how side branches develop when the terminal portion is removed. (Original photograph)

Origin of Cultivated Plants. Although we cannot go into details here, it is interesting to note in this connection the manner in which we have obtained the vast number of varieties of perennial plants that are commonly grown in any region. 1. Doubtless a very large number were taken directly from the wild where they were growing, such as the Concord grape, certain blackberries, and dew-

berries. 2. Sometimes under cultivation, a seedling appears that proves very valuable. Mr. Gideon of Minnesota planted hundreds of thousands of apple seeds, and finally obtained one type of excellent value, — the Wealthy apple. 3. Some varieties we now have



FIG. 73. A WOUND UPON AN ELM CAUSED BY THE REMOVAL OF A BRANCH

Note how the wound is cracked. It was painted only once. (Original photograph)

are crosses between other cultivated types, as is the case with several varieties of grapes. 4. At times buds on a plant vary and thus give rise to distinct varieties, as is the case with some of our common apples. The varieties that originated in these ways are propagated by budding and grafting, or in other ways essentially similar.

Care of Young Budded Fruit Trees. Often in the production of young grafted trees the stocks or rooting parts are of seedlings, or perhaps of a type of plant very different from the desirable variety from which the bud or scion was taken. Sometimes buds appear *below* the graft on the young tree and develop rapidly, thus injuring those higher up. Such a bud will produce a tree similar to the stock from which it originated. Consequently all these should be destroyed as soon as they appear.

Buds are likely to develop below the graft if the wound due to the grafting failed to heal properly, or if the stem was severely injured and thus the free passage of sap interfered with.

Vegetative Propagation. 1. *Cultivated plants.* Vegetative propagation refers in general to the production of new plants

through the growth of some part of the parent plant other than the seed. The roots and the stems very frequently function in this way. The scions used in grafting, the cuttings of geraniums, the pieces of the potato tuber used in the production of these plants, and the root of horseradish, are good examples of the structures used by the gardener in multiplying plants by this method.

2. *Wild plants.* Vegetative propagation is very common in wild plants and, in many cases, it is the chief means by which such species spread. *Roots* often run considerable distances and, at intervals, give off shoots that develop. Thus clumps of such plants, for example, Canada thistles, and sumac, are of frequent occurrence. Sometimes plants such as white clover have *stems* that run along the surface of the soil, root here and there, and send up leaves and blossoms. In other cases the stems are more or less specialized and pass through the soil, forming *underground stems*, as in the Canada blue grass and some of the common bindweeds. Some form special *runners* that extend out from the crown of the plant and root at certain definite places, after which the branch dies off leaving the new plant to grow independently. Such is the case with the strawberry. With some, as the raspberry for example, the long slender *branches* bend over and strike root near the ends, thus forming separate plants. (Figs. 76 and 77.)

3. *Lower plants.* With many of the lower forms of plants, such as bacteria and yeasts, vegetative reproduction is often of the highest importance. In fact, this type of multiplication is, upon the whole, more general in its occurrence throughout the plant kingdom than



FIG. 74. — A CAVITY IN AN OAK THAT HAS BEEN FILLED WITH CEMENT (Original photograph)

the sexual type which involves the process of fertilization, and the formation of seeds or sexual spores.

Comparison of Vegetative and Sexual Reproduction. New plants formed by vegetative reproduction are generally very much like the parent. This is what we should expect, for they are really parts of the original plant which come to lead a separate existence. Consequently, the characters of the single parent very generally appear in the offspring. This is in direct contrast to sexual repro-

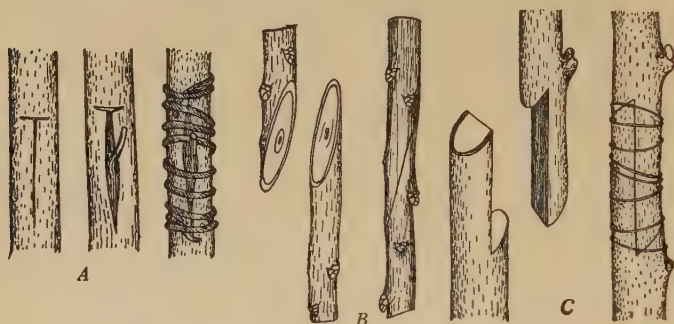


FIG. 75.—VARIOUS METHODS OF GRAFTING

A, budding; B, a contact graft; C, a form of saddle graft.
After Gaucher. (From Allen and Gilbert's *Textbook of Botany*)

duction, for here the new plant has its origin in the union of two sex cells which may and frequently do carry very different hereditary qualities. Thus in plants that are generally cross-pollinated, as was shown in a previous chapter, there are likely to be wide variations in the offspring unless great care is observed in keeping the seed true to type. It is true that variations may occur at times when vegetative reproduction is the rule, but these variations are generally small in comparison to the others, and seldom materially affect the desirable characters of the plant. On the whole, it is very much easier to retain a desirable set of characters in a given variety by vegetative rather than by sexual reproduction.



FIG. 76. ROOT STALK OF CANADA THISTLE SHOWING THE CHARACTERISTIC METHOD OF PROPAGATION (Original photograph)



FIG. 77. — WHITE CLOVER SHOWING THE STEMS THAT RUN ALONG THE SURFACE OF THE SOIL AND SERVE TO SPREAD THE PLANT (Original photograph)

LEAVES

Parts of a Typical Leaf. Typical leaves, such as are present on many of our forest and fruit trees, are composed of a wide, expanded portion — the *blade* — and a slender stem-like part — the *petiole*. Sometimes, as with the clover or rose, there are small, more or less leaf-like structures at the base of the petiole, known

as *stipules*. Some plants, as the wild lettuce and others, have leaves whose blades are attached directly to the stems. Such are said to be *sessile*.

Forms of Leaves.

Leaves vary greatly in shape and size. Those of the common grasses and pines are very long and slender, while those of the catalpa or sunflower may be as much as a foot or even more across. Many, known as *simple leaves*, as in the geranium, consist of a single blade; and others, called *compound leaves*, are made up of a number of separate small leaves, called *leaflets*, borne upon a common petiole, as is the case

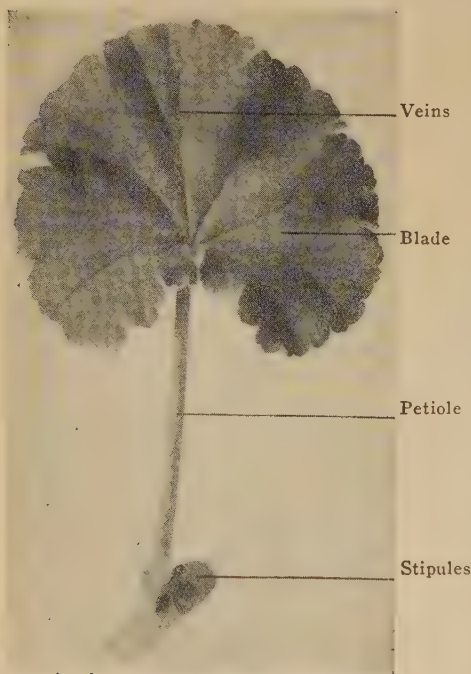


FIG. 78. — PARTS OF A LEAF (Geranium)
(Original Photograph)

with the rose, ash, clover, and others. In fact, leaves vary so much in form, size, margins, and texture, that in a text like this a mere mention of these differences seems sufficient. (Figs. 79 and 80.)

Arrangement of Leaves upon the Branch. Leaves occur in

certain definite orders upon the stems. Those that appear in pairs, one upon either side at a node are said to be *opposite*. This is the case with those of the lilac, maple, and many others. If three or more arise at a node forming a circle about the stem, as in some hydrangeas and numerous wild plants, they are referred to as *whorled*. In many plants, the leaves occur singly at the nodes and are arranged alternately. Such are said to be *alternate*. Very



FIG. 79. — MARGINS OF LEAVES (Original photograph)

often, especially in vertical stems, alternate leaves take on a *spiral* arrangement. Rapidly growing shoots of apple show this order of occurrence to good effect. (Figs. 81 and 82.)

The Veins of Leaves. The veins of leaves consist essentially of fibrovascular bundles, together with certain cells that add rigidity to the structures. The bundles extend down through the petioles and connect with tissue of the stem and thus form continuous passageways for the distribution of the substances absorbed in the roots. There are two general types of veining found in our common plants. The leaves of the apple, geranium, and a large number of others are said to be *net veined*; that is, these structures form a more or less definite network throughout the blades. In other cases, notably corn, wheat, and our common grasses, the veins run practically parallel to each other; hence these leaves are said to be

parallel veined. Leaves of this type are often long and slender, while those having net veins are generally much broader.

Functions of Leaves. *Photosynthesis.* The characteristic function of the green leaf is the production of food. It is here that photosynthesis, in general, occurs. Sometimes green stems, as in garden asparagus, may carry on this work; but with most plants photosynthesis in the stem is not very important, although it fre-



FIG. 80. — SOME COMPOUND LEAVES (Original photograph)

quently occurs near the growing points where chlorophyll is often present. The internal structure of the leaf, as well as the arrangement of leaves upon the plant relative to the light, is correlated with this important function.

Other Functions of the Leaf. Leaves have several functions of more or less importance. *Transpiration*, or the evaporation of water from the plant, takes place largely through the leaves. This loss of water from the plant, may and often does occur from other parts, as young stems or exposed roots. With some plants the

leaves may serve for the *storage of water*, as in the live-for-ever; but this function is also shared by the stems, as is notable in the cactus, and others that thrive in dry regions. Green leaves also serve generally for a temporary place of *storage for the food* that is made during the day. This last-named function may be demonstrated by treating a green leaf during the latter part of the day with iodine, when an abundance of starch may generally be found



Alternate

Opposite

Whorled

FIG. 81. — ARRANGEMENT OF LEAVES UPON THE BRANCH

(Original photograph)

present. During the night this starch may be largely transported to other parts of the plant. Some plants, as the begonia, may be *propagated by means of the leaves*.

Importance of the Leaves. As the production of food is fundamental to the life of the plant, any injury to the leaves while they are active in photosynthesis must be of far-reaching importance. Thus, the destruction of the leaves of corn or wheat by insects, hail,

and the like, is certain to cut off entirely, or, at least, to reduce materially the food supply and hinder the filling out of the grain. Some plants, such as the Irish potato, and forest trees, that ordinarily store large amounts of food in the stems or other parts, may be able to send out a new growth of leaves, after the first has been destroyed by frost or insects. But even with these, the repeated loss of the leaves will eventually prove fatal.



FIG. 82. — RELATION OF LEAF ARRANGEMENT TO BRANCH ARRANGEMENT (Elm)
Note that the leaves, buds, and branches are similarly arranged. (Original photograph)

Internal Structures of the Leaf. The leaf, as in case of the stem, is a complicated structure; but a careful study of Figure 83 will aid much in making clear the more important parts. The section from which the drawing was made that is reproduced in this figure, was cut at right angles to a vein, and shows the important parts of a typical leaf.

The upper surface of many leaves is covered by a thin, waxy

coating known as the *cuticle*, which serves to prevent the escape of water from the tissues beneath. The *epidermis* is made up of a single layer of cells that lie immediately beneath the cuticle and form a continuous layer over the entire surface. A similar layer exists upon the lower side of the leaf. Between the two layers of epidermis are the important tissues of the leaf. The upper part of this interior region is occupied by several layers of thin-walled, elongated cells that are closely joined together with their longer

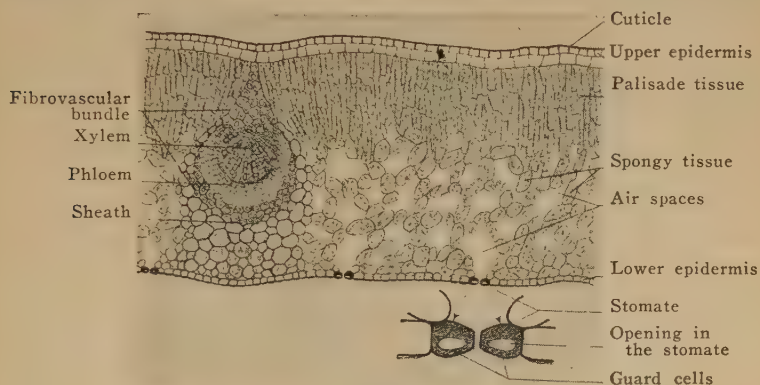


FIG. 83. — LEAF STRUCTURE

Cross section of a leaf through a fibrovascular bundle.
Highly magnified. (Original)

dimensions at right angles to the epidermis. These form a rather compact tissue known as the *palisade tissue*. Within these cells are numerous green chlorophyll bodies, or *chloroplasts*, as they are often called. The presence of these bodies in great numbers indicates that this tissue is very active in carrying on photosynthesis. Just below the palisade layer and extending to the lower epidermis is a region made up of *spongy tissue*. This is formed of thin-walled cells which are very loosely put together and which leave large open air spaces. These cells contain some chloroplasts, and doubtless also function in food making.

Stomates. In the lower epidermis, and sometimes also in the upper, although generally in much smaller numbers, are very numer-

ous, minute openings, known as *stomates*, that form continuous passageways between the air in the spaces of the spongy tissue and that which is outside. Each minute opening is guarded, so to speak, by two kidney-shaped cells, called *guard cells*, that under certain conditions may enlarge or close the opening into the interior.

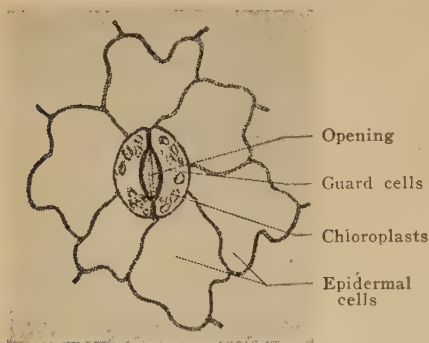


FIG. 84.—STOMATE FROM GERANIUM Surface View. (Original)

(Fig. 84.) Often the stomates open directly upon the surface of the leaf, as with many of our common plants; but sometimes they are in pits of various sorts or protected in other ways, as is often the case in plants of dry regions, where evaporation is excessive.

Structure of Veins.

The interior of a vein is rather a complex structure; but the essential part, the *fibrovascular* bundle, is not very different from those of the stem. The xylem region, which is near the upper side of the bundle, is made up of a number of well-defined ducts or tubes that function in carrying the water into the leaf tissues. Below this is the *phloem* region: This, as with similar tissue of the stem, is concerned with transportation of the enriched sap. About these two regions may sometimes be found tissues that add to the rigidity of the vein, and thus aid in holding the leaf in shape. The minute veins are so close together that every cell on the interior of the leaf is in close communication with the bundles.

Photosynthesis. Its Importance. Photosynthesis is one of the most fundamental of all processes in living things. As was stated in Chapter I, all food, capable of providing energy in the plant or animal body, originates in this process. Consequently, living things, almost without exception, can exist only when provided with a supply of nutrients produced, directly or indirectly, by photosynthesis.

The Process of Photosynthesis. In the process of photosynthesis two simple substances, *water* and *carbon dioxide*, are used. The water is taken into the plant through the root hairs and carried to the leaves in the ducts of the xylem and finally reaches the palisade and spongy tissues. The *carbon dioxide*, which is present in the air in minute quantities, passes into the leaf through the stomates, comes into contact with the moist cells on the interior, and finally reaches the chloroplasts found so abundantly in this tissue. Some of the *sun-light* that strikes the leaf is absorbed and utilized in building up a simple sugar, *glucose*, out of the water and carbon dioxide.

The Definition of Photosynthesis. The process of food making is very complex, but this much is perfectly clear, that the chlorophyll in the living cells of the plant is able to bring about this important result. *Photosynthesis, then, may be defined as the complex process that takes place, in general, in the living cells of the green plant whereby sugar is built up out of carbon dioxide and water through the activity of chlorophyll.* (Fig. 87.)

The Chemistry of Photosynthesis. It will be recalled that the chemical formula for glucose is $C_6H_{12}O_6$, and that of carbon



FIG. 85. — PLANTAIN LEAF

Right — Under side showing the prominent veins. *Left* — Petiole broken in a way to show the relation of the fibrovascular bundles to the veins. (Original photograph)

dioxide, CO_2 , and water, H_2O . All of the elements found in glucose are present either in the carbon dioxide or in the water, but the relative total amount of oxygen in these substances taken together is greater than in the glucose. This is apparent from the



FIG. 86. — OXYGEN FROM PHOTOSYNTHESIS

The funnel contains a green water plant. At the top is a test tube arranged in such a way as to collect the bubbles of gas given off when the apparatus is in the sunlight. See text for discussion. (Original photograph)

in tissues where the process is going on; for very soon it is transformed into starch. The starch remains in the cells only temporarily, for later it is changed into glucose again and carried to the various parts of the plant for immediate use, or for storage. The phloem regions of the bundles are active in the transportation of the glucose.

Origin of the Other Nutrients. The carbohydrates produced in photosynthesis are the basic substances out of which the other nutrients are built up. Fats contain the same elements as the carbohydrates, but a relatively smaller amount of oxygen is present.

chemical equation that expresses the relation of these elements in the formation of glucose out of carbon dioxide and water, $6\text{CO}_2 + 6\text{H}_2\text{O} = \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$. In other words, when *glucose is formed in photosynthesis, there is some oxygen left over*, which is given off in the free state. This escape of oxygen during the process of food making in the plant, may be easily detected by observing in bright sunlight a green, submerged water plant. Under these conditions bubbles of this gas usually appear in abundance.

The Food Produced. During the early stages of photosynthesis, evidence indicates that simpler substances are produced, but glucose is the final product. This substance, however, is not the one most easily demonstrated

It appears that the living substance of various cells in the plant may build up this nutrient from the sugar. Likewise the proteins are produced; but here several additional elements are necessary, notably, nitrogen, and frequently phosphorus, and sulphur. These are provided by the compounds, such as nitrates, that are absorbed from the soil water by the roots and carried to the various tissues where proteins are formed.

Energy Relations in Photosynthesis.

The most fundamental result in the production of food is the transformation of the sun's energy into a form available for living things. When carbon dioxide and water are combined in the leaf, some of the *sunlight is absorbed and held in the sugar as chemical energy*. This may be released and appear in some form by

breaking down the complex food substance. If sugar is burned in air, carbon dioxide and water are produced, and the energy appears as light and heat. If the reduction takes place in the plant or animal body, through respiration, the energy appears as heat or motion, or in some more obscure form.

Energy in Fats and Proteins. When fats and proteins are built up out of the carbohydrates, the energy is not released, but remains in the new substances formed. Consequently, these may also be utilized as a source of energy by living things. If the food is transformed into tissues, such as wood or cellulose, the energy is still retained and consequently, these, as well as most other organic substances, may be oxidized with the release of energy.

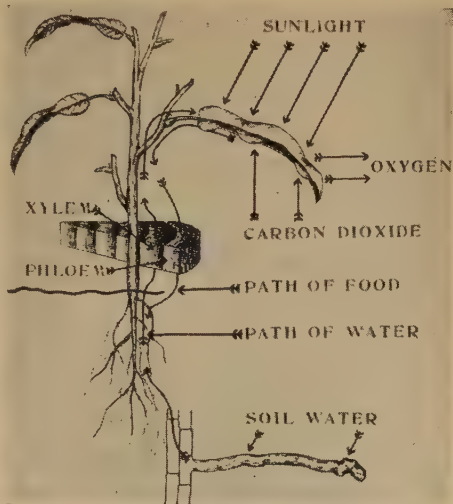


FIG. 87. — DIAGRAM OF PHOTOSYNTHESIS
(From a wall chart by the author)

Photosynthesis and Respiration Compared. These two important processes are both concerned with the food. In photosynthesis food is built up, energy is stored, carbon dioxide and water are used, and oxygen is given off. On the other hand, in ordinary

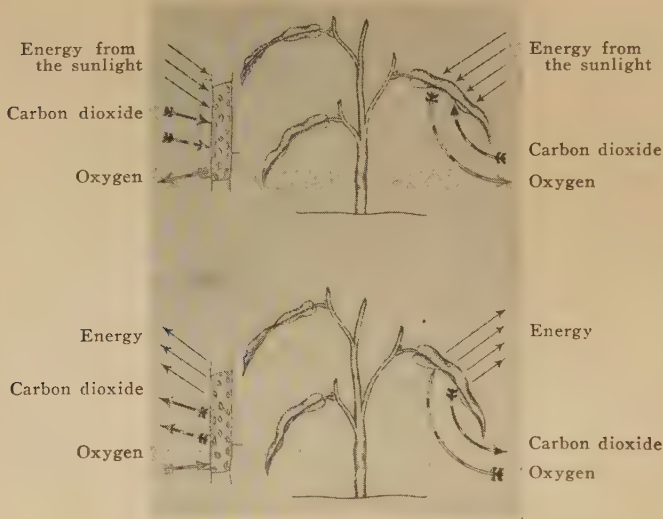


FIG. 88. — PHOTOSYNTHESIS AND RESPIRATION CONTRASTED

Above — Photosynthesis. *Below* — Respiration. *Left* — A single cell.
Right — A plant leaf. (Original)

respiration food is broken down, energy is released, carbon dioxide and water are given off and oxygen is used. Photosynthesis takes place only in the light, and in cells containing chlorophyll; while respiration occurs, not only in the light, but also in darkness, and in all living cells. (Fig. 88.)

Respiration and Photosynthesis in Green Plants. With green plants in the growing state both processes occur at the same time in the light; but in darkness only respiration takes place. Consequently, green plants take in oxygen and give off carbon dioxide at night just as animals do, but in the light, the reverse is apparently the case; that is, carbon dioxide is absorbed and oxygen

is given off. This is due to the fact that photosynthesis is very active in bright light, and consequently, its results obscure those of the respiration that takes place in the cells at the same time. Figure 88 will serve to make this discussion clear, both with respect to a plant as a whole, and to a single living cell.

Transpiration. Transpiration may be defined as the evaporation of water from a plant. The total surface exposed to the air by the leaves of our common plants is very great and, consequently, most of the transpiration takes place through these structures. The young stems also give off water. A leafy plant arranged, as shown in Figure 89, serves well to demonstrate transpiration. The sheet rubber about the pot and covering the soil prevents loss from these surfaces; consequently, any decrease in weight is due to the loss of water through the exposed parts of the plant. A plant arranged in a similar way and placed under a large bell jar may also be used to good effect. Here some of the transpired water collects upon the interior of the jar. The rate of the loss of water in transpiration depends largely upon the condition of the surrounding air.

Factors that Control the Evaporation of Water in the Air. There are several atmospheric conditions that influence the evaporation of water in a marked way and, consequently, these are of



FIG. 89. — APPARATUS ARRANGED TO INDICATE TRANSPIRATION IN A GERANIUM PLANT

The surface of the soil and the pot are covered with sheet rubber to prevent the loss of water from these surfaces. See text for discussion. (Original photograph)

importance relative to transpiration. 1. The *humidity* — that is, the amount of water vapor in the air — has much to do with the rate at which evaporation takes place. As the air becomes more nearly saturated with water, the rate decreases, and, conversely, the drier the air, the higher the rate. 2. *Heat*. Warm air is able to hold much more water vapor before becoming saturated than cold air. Consequently, since heat increases the capacity of the air for



FIG. 90. — TRANSPIRATION AND WILTING

Left — A wilted *Coleus* plant. *Right* — The same plant revived through the use of a bell jar arranged as shown in the cut. See text for discussion. (Original photograph)

water, evaporation is likely to take place more vigorously at higher temperatures than at lower. The air in early morning may contain just the same amount of vapor per cubic foot as the warmer air at noon, but the latter is much drier because of its greater capacity to hold moisture; hence evaporation is more rapid under the latter conditions. 3. Air in *motion* is likely to be much less humid than still air; consequently circulation of the atmosphere

increases evaporation. The layer of still air over water soon becomes very moist and acts somewhat as a blanket in preventing the drier portions from coming into contact with the surface.

4. The *extent of exposed surface* is also an important factor in determining the rate of evaporation. An ounce of water in a dinner plate, disappears much more rapidly than the same amount placed in a deep vase.

The Influence of the Condition of the Air upon Transpiration. The factors just mentioned as influencing evaporation are of the highest importance relative to transpiration in plants. Thus transpiration is much more rapid in dry, than in wet weather; during the warm hours of the day, than in the cool of the morning; and in windy situations, than in protected places. In fact, in some regions evaporation often becomes so excessive during the continuation of dry, hot winds of the summer, that vegetation dries up and is often killed outright.

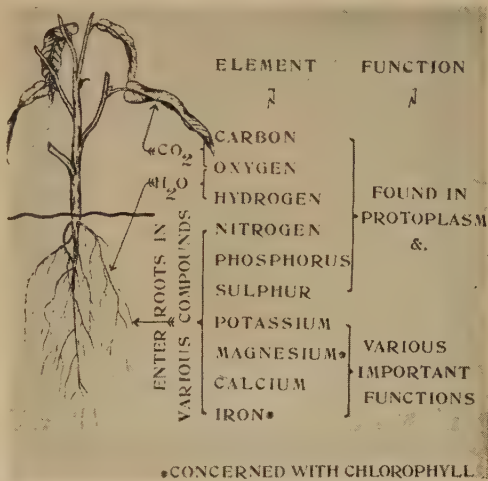


FIG. 91. — ESSENTIAL ELEMENTS FOR PLANT GROWTH

The arrows indicate where the various elements enter the plant. (From a wall chart by the author)

Wilting of Plants.

As was pointed out in a previous chapter,

the tender young tissues of plants are held rigid by the pressure of the water in the cells, known, in general as *turgor*. If, for any reason, this water is decreased in amount to any great extent, the tissue loses its freshness; or in other words, it wilts. Under ordinary conditions, the amount of water taken in through the roots balances, in a rough way, that lost by transpiration. If, for any rea-

son, more is lost than is taken in, as is frequently the case during the hot part of the day when the soil is very dry or when a large portion of the root system is injured, the plant wilts.

Effect of a Light Shower upon Wilting of Plants. Sometimes a change in the humidity of the air causes a marked change

in a wilted plant, as when a very light shower, not enough to wet the soil at all, but sufficient to increase the humidity of the atmosphere, results in a rapid freshening of the leaves and tender stems. This is due largely, not to the entrance of more water through the roots, but to the decrease in the loss from the leaves as a result of the higher humidity of the atmosphere. The reduction of the leaf surface, by pruning reset plants, finds its chief immediate benefit in the checking of the loss of water when the roots are unable to furnish a

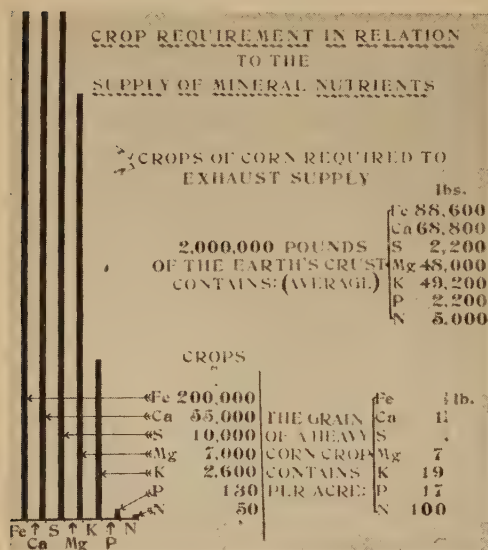


FIG. 92. — MINERAL NUTRIENTS AND CROP PRODUCTION

The columns at the left represent graphically the amounts of the various elements in the earth's crust. (From a wall chart by the author. The data used is obtained from *Soil Fertility and Permanent Agriculture* by Hopkins, published by Ginn and Co. By permission.)

sufficient supply. The practice of covering reset garden plants with jars, also acts much in the same way; but here the evaporation is checked by the increase of the humidity in the air within the jar.

How Water Escapes from the Plant. Transpiration takes place largely through the stomates of the leaves or young stems,

to a much less degree by way of the *lenticels*, — the tiny openings in older stems, — and only in minute quantities through the uninjured cuticle or cork.

How Plants Prevent the Loss of Water. The ordinary plant growing in a soil where water is likely at times to be deficient in quantity, is generally fairly well protected from excessive loss through transpiration. The larger roots and the body of the plant, in the case of trees and shrubs, are generally covered by a layer of cork that is practically impervious to the passage of water. The young stems and the leaves are often coated with a thin layer of *cuticle*, a waxy substance through which moisture escapes with difficulty.

Stomates and Water Loss. In dry times, stomates frequently become a serious menace to the plant through the loss of water. Consequently forms growing in dry regions often have the stomates located in deep pits, or protected in other ways — an arrangement which tends to prevent the loss of water. Moreover, the guard cells under certain conditions may close, or at least, decrease the size of the openings, and thus in a rough way tend to control water loss. Some desert plants are especially adapted to conserve water in a variety of ways, such as by the presence of water storage tissue, reduced leaf surface, and heavy cuticle. Plants that live in water or very moist situations are poorly protected, and as a result, they often wilt quickly when exposed to dry air.

CHEMICAL ELEMENTS AND PLANT GROWTH

Essential Elements for Plant Growth. There are ten chemical elements recognized as essential for the growth of the green plant: namely, carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and iron. Three of these are present in the water and carbon dioxide used in photosynthesis. The others are taken in from the soil water where they occur in various soluble compounds. It is important to understand that *every one of the ten elements must be present in suitable forms*, if plant growth is to take place.

Uses of the Various Elements in the Plant. *Carbon*, *hydrogen*, and *oxygen* are the only elements occurring in carbohydrates and fats, and they also make up a large part of the various kinds of protein. Substances formed from the foods, as protoplasm, and those of a structural nature, like cellulose and wood, are also rich in these elements. *Nitrogen* is always present in protein; and *phosphorus* and *sulphur* are of frequent occurrence in this class of nutrients. Since protoplasm is composed of a mixture of proteins, it is clear that these elements must always be present. The other four — *iron*, *potassium*, *magnesium*, and *calcium* — have important special functions to perform, but these need not be discussed at present. (Fig. 91.)

Sources of the Mineral Elements. All of the essential elements, except carbon, hydrogen, and oxygen — which are taken into the plant as described under photosynthesis — are obtained from the solid portions of the soil which become dissolved in the soil water. With the exception of nitrogen, which finds its way into the soil through the decomposition of organic matter, the mineral elements — namely, phosphorus, potassium, sulphur, magnesium, calcium, and iron — are present in the decomposed rock materials. These elements continually decrease in soils where crops are grown unless they are added from outside sources. The nitrogen supply is also generally on the decrease in tilled lands. This element, however, may be increased through the bacteria of the root nodules of legumes, which draw from the inexhaustible supplies in the air.

Insoluble Minerals in the Soil. The supply of minerals in the soil is of great importance relative to the permanent production of crops. A very large proportion of these, in general, are in insoluble compounds in the rock particles and in other soil constituents. Plants cannot use these elements until they are changed into suitable forms. When compounds are in forms such that they can be absorbed and utilized by plants, they are said to be *available*.

The Amount of Minerals Removed by Crops. The question as to how rapidly the supplies of the various minerals are diminished by the production of crops is of the highest importance.

The seeds, as well as the other parts of plants, always contain these elements in considerable quantities. Consequently, when grain, hay, or other plant products are taken from the land there must be some reduction in the supplies of these essential elements. If the amount removed is considerable and the quantity in the soil is limited, then after a time, these substances will be insufficient for the production of crops. Such a soil is looked upon as worn out, or *sterile*. (Fig. 92.)

The Deficiency of Nitrogen. A bushel of shelled corn contains about one pound of nitrogen. A heavy crop, as for example, one of a hundred bushels per acre, when removed from the land, will carry away something like a hundred pounds of this element. In the surface soil of an acre of our best land there is not more than four or five thousand pounds of nitrogen at the most; and generally the supply is much less than this. It follows from these facts that continual cropping without an addition of nitrogen from without would reduce this element, in a generation or two, to a point where it would be insufficient for the production of corn. Consequently the crop would be cut off. The reduction in the amount of nitrogen, due to the removal of crops, does not continue at the same rate year after year; for, as the element becomes more and more deficient, the production of grain decreases and, consequently, less nitrogen is carried off in this way.

The condition just described is exactly what has happened in large areas of agricultural lands all over the country, until now in many localities it is impossible to raise crops successfully without first adding nitrogen to the soil in one way or another. Some other elements become deficient in the soil in much the same way as nitrogen.

The Elements Most Likely To Be Lacking in the Soil. It is difficult to determine the abundance of the essential elements in the soil relative to plant growth. Large proportions of some of these occur in forms that are insoluble and that do not readily become available. Consequently even when an element may be abundant, the plant may not be able to absorb what it needs, and its growth is affected in the same way as when the substance is de-

ficient. This condition is not infrequent with some of the elements, as for example, phosphorus and potassium.

On the whole, however, the elements most likely to be deficient, or at least lacking in available forms, are *nitrogen*, *phosphorus*, and *potassium*. Certain other substances, as limestone (calcium carbonate) for example, are frequently necessary in the soil; but these generally function in other ways than to supply the necessary elements for growth. Sterile soils are often deficient in one or more of these elements, although other conditions frequently enter in that check production. Among these are sour soil, poor drainage, and the like.

Organic Matter and the Fertility of the Soil. The organic matter in soil has two very important functions relative to fertility and the production of crops. 1. As organic matter most frequently occurs, it is made up largely of plant remains. This is true from whatever source the material is derived, whether from weeds, or cornstalks, or indirectly, as from stable refuse, which consists of undigestible or partly broken-down plant products, mixed with straw and the like. Since organic matter originates largely from the structures of green plants, it is clear that some of the essential elements are returned to the soil by the addition of this material. This renewing of the essential elements in the soil is one of the important functions of organic matter as a fertilizing agent. 2. When the organisms are growing in the organic matter, thus causing decay, certain substances, such as carbon dioxide, are produced in abundance. The carbon dioxide is taken up by the water in the soil and thus comes into contact with insoluble rock particles, which are acted upon in such a way as to produce simple compounds that plants can use. Organic matter, then, through the carbon dioxide that is formed in the process of decay, serves to make available for plant use the elements held in the insoluble rock particles. These relations are shown in a diagrammatic way in Figure 93, which diagram should be carefully studied.

The Legume as a Source of Organic Matter. Bacteria within the nodules upon the roots of the legumes, such as clovers, alfalfa, beans, and peas, have the power of utilizing the nitrogen

from the inexhaustible supplies of the air. As a result the tissues of these plants, and consequently the organic matter originating from this source, are especially rich in this element so often lacking in the soil. The legume crop that is plowed under, thus adding to the soil large quantities of vegetable material, is without doubt the most satisfactory means to increase the nitrogen content on a large scale for the use of succeeding crops.

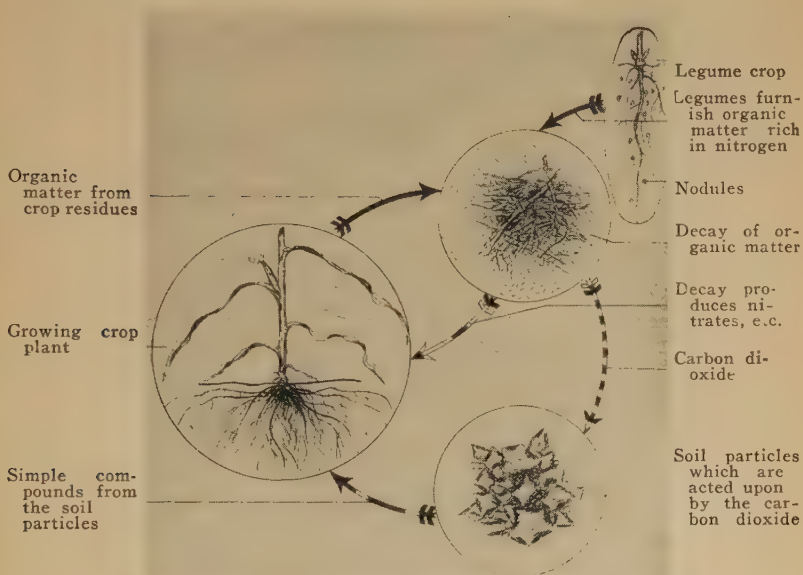


FIG. 93. — DIAGRAM SHOWING THE RELATION OF LEGUMES AND ORGANIC MATTER TO PLANT GROWTH

(Original)

In order to add nitrogen to the soil most rapidly, it is necessary to plow under the entire plant — root, stem, and leaves. In fact, if the stems of clover, for example, are removed as hay, the nitrogen content of the soil is not increased to any marked extent, for the amount of this element in the hay approximately equals that taken from the air by the clover bacteria.

Conditions Favoring the Growth of Legumes. It is often difficult to get some of the legumes, as certain clovers, and alfalfa, to grow upon land that has been cropped for long periods, or upon soil where the crop has not grown before. This may be due to any one of several causes that interfere with the growth of these plants.



FIG. 94.—UPPER PORTION OF THE ROOT SYSTEM OF ALFALFA SHOWING THE DISTRIBUTION OF NODULES (Original photograph)

1. The proper kind of bacteria may not be present in the soil. If this is the case, it is necessary to inoculate the land, that is, to add the necessary bacteria to the soil. This may be accomplished by moistening the seeds with a weak solution of glue and dusting them while still wet with fine dry soil that contains the bacteria in question. In this way each seed should carry some of the organisms necessary for the formation of nodules upon the developing root system.

2. Soils that have been tilled for long periods, are very likely to become *sour*; that is, certain acids gradually accumulate, and finally become sufficiently abundant to interfere with the growth of plants, especially of legumes. The very marked effect upon legumes is due

largely to the fact that the root bacteria do not thrive well in the presence of acids, and without these organisms the plants generally develop poorly or not at all. To remedy this condition, crushed limestone may be added to the soil, the effect of which is to neutralize the acid, and thus permit the growth of the bacteria.

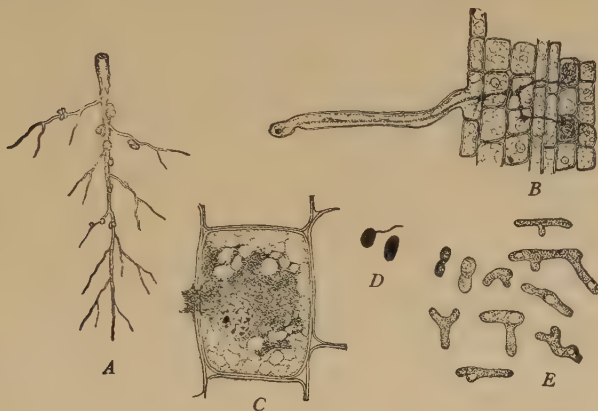


FIG. 95. — NITROGEN-FIXING BACTERIA

A, roots of a leguminous plant (such as clover), bearing many small swellings. *B*, the method of entrance of the bacteria through a root-hair, and their progress through the tissues of the clover. *C*, a single cell of a clover root containing many bacteria, which appear as small dark dots. *D*, single bacteria as they appear in an artificial culture. *E*, as they appear in a cell of the clover. (From Allen and Gilbert's *Textbook of Botany*, page 27.)

3. Often, even in some of the high-class soils, phosphorus is found to be more or less deficient, and the legume crop, as well as others, thereby fails to develop as it should. The remedy for the lack of phosphorus is the addition of this element to the soil in some form, such as in finely ground rock phosphate, bonemeal, or some other material.

Permanent Soil Fertility. A system of managing the soil so that crops may be produced indefinitely without bringing about a deficiency in any of the essential elements is obviously of the highest importance. The principles brought out in the preceding discussion,

if properly applied, are sufficient to produce this desired result. A careful study of Figure 96 will serve to make clear the main features

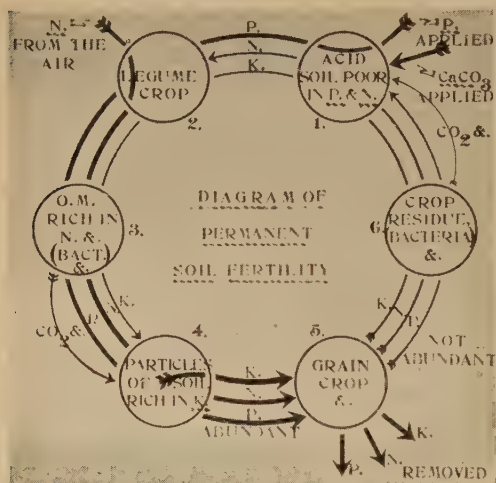


FIG. 96. — FROM A WALL CHART BY THE AUTHOR

See text for full discussion. The author is indebted to that great agricultural scientist, Cyril G. Hopkins, for the fundamental ideas involved in the above diagram.

acidity with crushed limestone, as shown in the diagram. At the same time phosphorus must be added, for this element is deficient and the legume crop that is to follow needs this in order to be able to make a vigorous growth.

The *second step* in this procedure is to grow a legume crop upon the land and plow it under, thus providing an abundance of organic matter rich in nitrogen. The decomposition of this material will give rise to nitrates, and other useful compounds for plant growth from the vegetable material itself. It will also produce carbon dioxide and other substances that will react upon the rock particles of the soil and make available new supplies of the essential elements found here. In this way the supplies of available phosphorus and potassium are made sufficient.

of a type of management that has been developed in recent years, and which is now being applied successfully on a broad scale to large areas of farming lands in the Middle West and elsewhere.

For convenience, let us assume that a piece of land is acid, and poor in phosphorus, nitrogen, and potassium.

The *first step* in building up this soil and starting a treatment that will make it permanently productive, is to correct the

As a *third stage* in the rotation, grain crops are produced, thus removing supplies of the various elements. There may be three, or possibly more crops, removed before a repetition of the above treatment is necessary. Sooner or later, however, the same round must be repeated, for the products that are removed carry from the soil the elements that readily become deficient.

The Permanence of the System Just Described. The system is essentially permanent, for the natural supplies of limestone and of nitrogen are inexhaustible, and the amount of phosphorus in the form of rock phosphate is very great. Moreover, the supply of potassium in the ordinary soil is also large, sufficient for thousands of crops at least, when made available through the decay of organic matter.

Commercial Fertilizers. In some regions commercial fertilizers are used upon the land as a means of maintaining the fertility of the soil. With these, the elements likely to be deficient in the soil are added directly, generally in an available form, or in a compound easily made soluble. The general principle underlying the use of these is the same as that discussed above; namely, that the crop removes some of the elements that finally become deficient and that such elements must be renewed if the soil is to remain productive.

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(One asterisk (*) indicates references suitable for students; two (**) those primarily for the teacher; three (***) those of especial value from the standpoint of the work covered in this text.)

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 - *** U. S. Department of Agriculture, Washington, D. C. (Send to the Superintendent of Documents for lists of bulletins and other publications that deal with insects, plants, birds, vertebrates, diseases, and foods, and select those desired. This material is extremely valuable for both teacher and student, and may be obtained at a nominal cost. Many bulletins may be obtained free through the United States Representative from the district in which the teacher lives.)
- (The Bibliography is continued at the end of Part Two.)

PART II — SPORE PLANTS

CHAPTER VII

ALGÆ AND FUNGI

GREEN SPORE PLANTS

Definitions. Plants in general may be thought of as belonging to one of two great groups according to their methods of reproduction: the *seed plants* and the *spore plants*. In the former group are placed those that reproduce by means of seeds, such as the various garden and agricultural plants thus far discussed in this book; in the latter are all of those that reproduce by means of spores, such as the mosses, ferns, mushrooms, yeasts, bacteria, molds, and numerous other forms. It is not easy in an elementary discussion to state accurately the differences between seeds and spores. It may be said, however, that a *seed* differs from a *spore* in that the former is a many-celled structure consisting of an embryonic plant together with a supply of food, while the latter generally is a single, specialized cell capable of reproduction. Both seed and spore plants often multiply by cuttings, runners, or through the growth of some other portion of the plant body. Such methods of propagation obviously are not concerned with either seeds or spores.

Groups of Green Spore Plants. A very brief statement con-

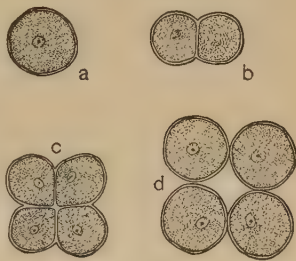


FIG. 97. — PLEUROCOCCLUS VIRIDIS

a, a single individual; *b*, *c*, and *d*, various stages in cell division. The chloroplasts are so crowded that no attempt has been made to distinguish them in the figure. (From Stevens' *Introduction to Botany*, page 270)

cerning the larger groups of green spore plants is advisable before taking up in detail certain non-green types, such as various fungi and bacteria, that are of the greatest importance to man. For the present purpose it is sufficient to refer to these classes as: 1. *Algæ*; 2. *Liverworts and Mosses*; and 3. *Ferns*. The plants belonging



FIG. 98. — A SINGLE CELL OF A SPIROGYRA PLANT

a, wall; *b*, outer layer of slimy cytoplasm; *c*, chloroplast, containing *d*, pyrenoids; *e*, nucleus, imbedded in a central mass of slimy cytoplasm which is connected by strands of the same substance with the outer cytoplasmic layer. (From Allen and Gilbert, page 40)

to these groups contain chlorophyll and consequently have the ability to make their own food, essentially the same as is the case with seed plants. The algæ are the only forms we shall consider here, and even these are of comparatively minor importance so far as human welfare is concerned.

Occurrence of Algæ. The algæ are very simple plants found abundantly in the water or in damp places almost every-

where. One common form, *protococcus*, often is present upon the trunks of trees which grow in moist situations. It produces a bright green coating upon the bark. Other forms, *spirogyra* for example, are frequently abundant in ponds or creeks and appear as long, hair-like filaments floating upon or near the surface of the water, sometimes covering considerable areas. Other species are found upon the shelves in greenhouses or upon watering troughs where there is a constant supply of moisture.

Structure of Algæ. The algæ, among the lowest plants, consist either of single cells or of groups of cells attached together in various ways, and differ from higher plants in having no structures of the nature of roots, stems, or leaves. The cells of algæ afford some of the best material obtainable for study under the microscope.

Importance of the Algæ. Directly or indirectly the algæ are of importance as a food supply of fishes. Some of the sea algæ were an important source of iodine in times past. Others furnish agar-agar, a gelatinous substance used largely as a medium upon

which to grow bacteria for purposes of study. Certain fresh water species are sometimes troublesome in city reservoirs, where they may impart disagreeable odors or flavors to the water.

Reproduction in the Algæ. Algæ multiply either by spores, which are formed in various ways by the parent plant, or by the breaking away of portions of the body, which start new colonies at a distance from the old plant. The

spores are rather diverse in character; some are formed directly from the protoplasm of a single cell, and some are produced as a result of the union of sex cells. Some types have definite power

of movement and swim about for a time before they grow, while other types simply float in the water and are thus scattered. Many algæ produce what are known as *resting spores* that are able to resist adverse conditions, such as drought or extreme cold, and thus keep the species from being killed off from year to year.

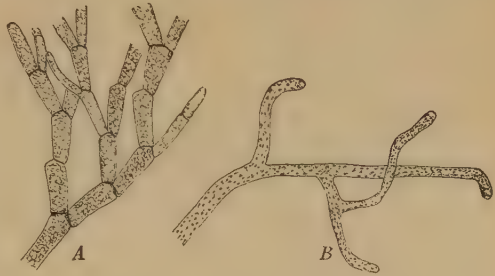


FIG. 99. — BRANCHED GREEN ALGÆ
A, *Cladophora*; B, *Vaucheria*. (From Allen and Gilbert, page 49)

NON-GREEN SPORE PLANTS

The non-green plants differ from the green plants in that they do not have chlorophyll, and consequently are unable to make their own food. In their food relations, therefore, the non-green plants are very different from the green plants with which we are familiar.

Food of the Non-green Plants. The absence of chlorophyll in the non-green plants is of the most far-reaching importance.

These types must, like all other living things, have a constant food supply; and since they cannot make it out of simple compounds, they must compete with animals, including man, for the

supply produced through photosynthesis in green plants. The non-green plants, taken as a group, destroy not only the foods used by man and the lower animals but also practically all other materials of an organic nature, such as wool, leather, wood, and innumerable others. They may, and frequently do, attack the tissues of the animal body itself, and thus produce injurious diseases.

Groups of Non-green Plants. Two groups of non-green plants are of high importance to man: 1. The *truc fungi*, and 2. The *bacteria*. The *fungi* are sometimes of considerable size, and, in

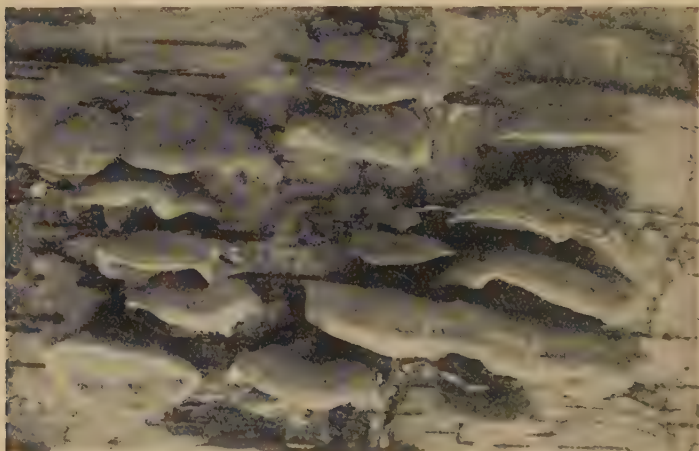


FIG. 100. — FRUITING BODIES OF A COMMON FUNGUS GROWING UPON A BIRCH (Original photograph)

the larger forms, often striking in appearance, as the mushrooms and the shelf-like fungi found upon trees. In other cases, the fungi may be very inconspicuous and reveal their presence chiefly through the effects produced; such, for example, are the forms that cause the rotting of fruits. Some forms, as the *yeasts*, which we shall consider with the fungi, are very minute — so small, in fact, that they cannot be seen at all with the naked eye. The *bacteria* include vast numbers of exceedingly minute, one-celled plants, too small to be seen except under the highest powers of the microscope. These forms generally grow in organic materials where they bring about

important changes. The odors and flavors of spoiled food substances, and the acids produced in milk and other foods are the results of bacterial action. (Figs. 100, 101, 102 and 128.)

Importance of the Non-green Plants to Man. *Injury.* No group of organisms, save the green plants upon which we depend for our food supply and other necessities of life, are so vitally related to human welfare as the non-green plants. Bacteria and fungi are the direct cause of a large proportion of diseases, not only of man and of domestic animals, but also of our plants as well. Moreover, they destroy our foods, cause the decay of timber, and are detrimental to man in many other ways.

Benefit. Yet bacteria and fungi are not only beneficial in the long run, but are even indispensable to life upon earth. The formation in the soil of compounds suitable for plant growth, the production of such valuable substances as vinegar and alcohol, and the production of desirable flavors in butter and cheese, are examples of the ways that certain forms are helpful to man. The most far-reaching value of bacteria and fungi centers about their ability to break down the complex organic compounds into carbon dioxide, water, and other simple chemical substances.

Substances Produced by Non-green Plants. The early stages of the breaking-down processes caused by these plants generally result in the formation of carbon dioxide and numerous, rather complex products, among which are alcohol, acetic and lactic acids, and other compounds having characteristic odors, frequently found in spoiled foods. Generally the process of decomposition goes on until finally simpler substances, such as carbon dioxide, water, ammonia, and nitrates appear. Respiration in animals and in green plants also aids in these reduction processes, but the result of the



FIG. 101. — A PUFFBALL, ONE OF THE COMMON FUNGI OF THE FIELDS. (From Allen and Gilbert, page 85)

respiratory process in higher forms of life is trivial compared to the results produced by the non-green plants.

Green Plants Depend upon the Non-green Plants. The reduction of the complex organic materials to simple substances is of the utmost importance. The building-up processes of green plants, as was pointed out in Chapter VI, depletes the supplies of the essential elements necessary for growth, while the non-green plants release these necessary substances in forms suitable for use in the building up of more food. Thus these two great general processes — the building up of food by green plants and the tearing down of organic matter by non-green plants and animals — work together to produce an *endless cycle or circulation of the essential elements in nature*. If the non-green plants should cease to perform this function, the earth would become littered with organic remains that could not decay, and consequently green plants could not exist. Thus life as we know it would vanish.

SOME TYPICAL FUNGI

BREAD MOLD

Occurrence and Appearance. In warm, moist weather, bread mold grows upon bread and numerous other foods, such as pumpkin, sweet potato, and banana. At first it appears as a fluffy, white growth upon the surface of the food. (Fig. 102.) Later, as the plants become older, especially if the surrounding air is in motion, the delicate, thread-like strands of which the growth is composed become compressed and form a felt-like mass upon the food substance, or *substratum*, a word often used to designate the materials upon which organisms of this type grow.

Structure of Bread Mold. Bread mold consists essentially of a tangle of very fine filaments which, taken as a whole, is called the *mycelium*. Scattered through and upon this fluffy mass are numerous fruiting bodies, or *sporangia*, within which the *spores* are borne. A single thread of the mycelium is a *hypha*. The hyphæ that enter the bread or other food substances are somewhat different from those upon the surface, and are often spoken of as *rhizoids*.

The Hyphæ. These hyphæ are extremely delicate structures consisting of very thin-walled tubes filled with granular protoplasm in which are numerous vacuoles containing water. The hyphæ that enter the substratum absorb water and other substances necessary for growth. Most other fungi have structures similar to these in form as well as in function.

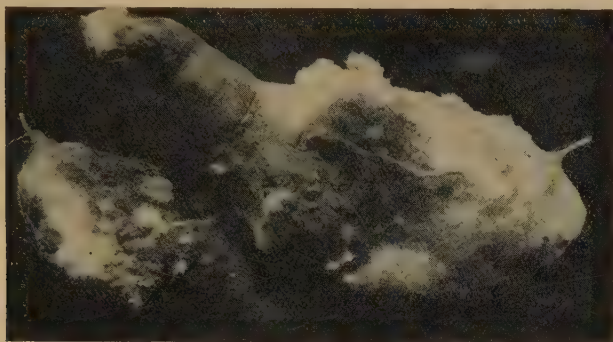


FIG. 102.—BREAD MOLD GROWING UPON SWEET POTATO
(Original photograph)

Penetration of Food Substances by Hyphæ. The active protoplasm secretes various enzymes which make soluble the materials of the substratum immediately in contact with the growing hyphæ. In other words, these delicate threads virtually dissolve their way through the substances in which they grow. In some species of fungi, such as those that grow upon trees, the hyphæ are able to penetrate very hard wood in this way. It is important to bear in mind that not only fungi but many other non-green plants as well, are frequently very active in the production of enzymes of various kinds.

Sporangia. The fruiting bodies of the bread mold are spherical in shape. They appear at the ends of more or less erect hyphæ, and are thus generally somewhat elevated above the main mass of the mycelium. A sporangium consists of a very delicate membranous outer wall enclosing the spores. Within the center is a thimble-shaped structure that terminates the fruiting hypha. (Fig.

almost jet black. At maturity, which is generally reached in a few days, the outer wall breaks up, releasing the spores in large numbers.

Spores. The spores of the bread mold are very minute, spherical structures of a dry, dusty nature, extremely well fitted for dissemination by currents of air, and exceedingly numerous, as are those of practically all other related fungi. The large number is necessary in order to insure the preservation of the species; for obviously a great proportion of the spores fail to find advantageous conditions for growth. (Fig. 105.)

Number of Spores Produced by Fungi. It is not uncommon for a single fruiting body of some of the larger forms, such as the mushrooms or puffballs, to produce billions, or, in some cases, even trillions of spores. The sporangia of the bread mold are also very numerous and very prolific of spores.

The abundance and wide dissemination of the light dusty spores make it easy to understand why bread and other foods mold so readily if suitable conditions for the growth of this fungus are present. For practical purposes it may be assumed that mold spores are always present everywhere in sufficient numbers to cause trouble with foods unless special precautions are taken to kill them, or to prevent their growth.

Function of Spores. Spores serve the purpose of reproduction. Under favorable conditions for growth, the spore sends out a hypha

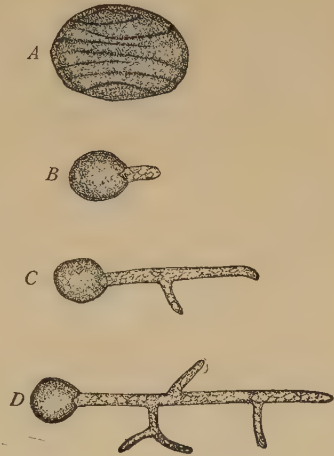


FIG. 104. — GERMINATION OF SPORES

A, a ripe spore of the bread mold, much enlarged. B, C, D, stages in the development of spores into young plants. (From Allen and Gilbert, page 56)

which elongates rapidly, and finally gives rise to the mycelium. (Fig. 104.)

Formation of Spores. The spores of bread mold are of two kinds, differing greatly in their methods of formation. 1. Spores



FIG. 105. — SIZE OF FUNGUS SPORES

The diameter of a human hair (*above*) and a fungous spore (*below*) magnified the same amount. (Original)

of the ordinary type, which serve for the immediate dissemination of the plants, are present wherever this mold grows. During the development of the fruiting body, the protoplasm breaks up into tiny portions, each of which becomes enclosed by a well-defined, resistant wall which serves well for the protection

of the living substance within. In this type of spore, there seems to be no sexual process involved. Fungi very generally form spores of



FIG. 106. — MOLD SPORES IN THE AIR

Left — Petri dish opened for one minute in a quiet room. *Right* — Dish opened for one minute in a room where much dust was in the air. The dishes were incubated later. (Original photograph)

this kind. 2. Under certain conditions the protoplasm of two separate mold plants may fuse and give rise to comparatively large

resting spores. These are often rare in this plant, but many other common fungi produce large numbers of resting spores that serve to carry the species from one season to the next. (Fig. 103.)

Moisture and Mold Growth. During the growing stages molds are much more sensitive to dry conditions than are green plants. The mycelium and the fruiting bodies contain a large proportion of water, and, as there are no structures to prevent loss of moisture the plants are very soon affected by dry air. This drying out does not soon destroy the life of the mold, but merely prevents growth until the proper amount of moisture is again present.

In contrast to the actively growing mold, the spores are able to withstand drying for a long time and still germinate. These facts explain why in moist, warm weather, molds, rusts, mildews, and other fungi appear so constantly and spread so rapidly where they have not previously appeared.

Heat and Mold Growth. *Low temperatures.* Molds and most other common fungi require considerable heat — temperatures ranging from 80° F. to 100° F. — for their maximum development. At 50° F. or 60° F. they grow but slowly, while temperatures near the freezing point stop them entirely. Low temperatures, although they prevent growth, do not necessarily kill the plants; in fact, many fungi live through the northern winters in decaying wood or in the soil where, doubtless, the mycelium is frozen for long periods. In general, low temperatures are effective in the preservation of foods by preventing the growth of fungi and bacteria rather than by destroying these organisms.

High temperatures. High temperatures are deadly to molds, either in the growing stages or in the form of spores. Water at 160° F., or even lower, quickly kills actively growing mycelium, but spores are much more resistant. In the preservation of foods by canning, the molds are killed rather than simply prevented from developing, as in refrigeration.

Other Factors Concerned in Mold Growth. *Direct sunlight* and the *movement of the surrounding air* seem to interfere with the growth of molds. This is probably due — in part, at least — to their effect upon the relative humidity of the air about the plants;

but apparently the sunlight itself, as well as the movement of the air, may have some direct effects upon growth. The *presence of oxygen* is essential for the growth of mold, doubtless in connection with respiration, which accompanies the very active growth processes that take place during development.

Other Common Molds. There are a number of other molds common upon food substances. *Penicillium*, or *blue mold*, as it is often called on account of the bluish or greenish color of the spores

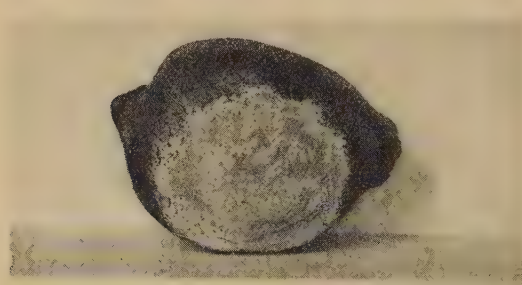


FIG. 107.—BLUE MOLD UPON A LEMON (Original photograph)

of some of the species, is often seen upon oranges, lemons, pumpkins, and numerous other articles of food in the pantry. The mycelium of this type is, generally, not so abundant and fluffy as that of the bread mold; and the

spores, which are very numerous, are borne in open, brush-like clusters from which they may sometimes be blown in such numbers that the air becomes colored with them. Another very common species, *aspergillus*, is striking in appearance because of the beautiful, bright colors displayed by the fruiting bodies of the various species. The spores are borne in open, spherical heads and may be jet black, various shades of brown, green, or yellow. In fact, one may look for almost any color where *aspergillus* is abundant. These, and various other common types, are similar in character to the bread mold and need no special discussion here.

Useful Molds. Some molds are of high commercial value in that they are indispensable in the manufacture of certain foods, notably cheese. During the ripening process, molds grow in this product and bring about changes that impart some of the characteristic flavors.

WOOD-DESTROYING FUNGI

General Character. The large fungi that grow upon timber serve well to represent a type distinct from the bread mold. Although they seem to be so different from the fungus just described, the two types are alike in many important respects. The wood-destroying fungi consist primarily of extensive mycelia that either spread through the wood upon which this fungus is growing, or

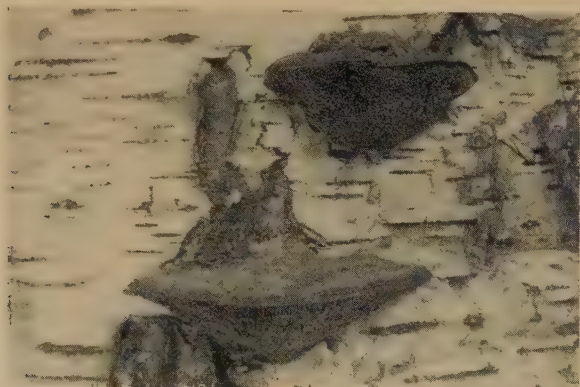


FIG. 108. — FRUITING BODIES OF A COMMON FUNGUS THAT GROWS UPON DEAD WILLOWS, BIRCHES, AND OTHER TREES (Original photograph)

become compact and form the characteristic fruiting bodies common upon diseased trees. (Fig. 108.) The spores, although borne in a very different manner from those of the bread mold, are, in general, quite similar to them in size, form, and function. The facts concerning the growth of the plant, its nutrition, and the character and distribution of the spores in the bread mold apply to these forms as well.

Occurrence. Many of the species of wood-destroying fungi grow upon dead or decaying timber, where their presence may be recognized by the appearance of the fruiting bodies, or by the mycelium that sometimes forms felt-like masses in the rotting wood. More important to us, however, are the numerous forms that develop

upon living trees, where they often cause the decay of the heart wood and eventually cause death. They destroy large numbers of forest and fruit trees. A half hour spent in almost any piece of woodland, or even along a shady street, will show the observer how frequently the loss of valuable trees is due to infection by these fungi.

Entrance into the Tree. Wood-destroying fungi are not able to enter the body of a tree through the uninjured bark. A wound that breaks through the dry, corky layers of the bark and reaches the inner tissues, makes it possible for the spores to lodge, and, under suitable conditions, to germinate. The hyphæ thus produced grow and penetrate the wood in all directions. The original wound may heal over, as indicated on page 132, and the tree may appear to be perfectly sound, while the mycelium continues to cause decay in the interior. If the wound does not heal over often a hole leads into the interior, allowing water to enter and hastening the decay.

Growth of Mycelium in the Trunk. The mycelium may grow for years in the heart wood of a tree without visibly affecting its external appearance. Such is the manner of growth of the trunk (Page 127) that the entire heart wood may decay, leaving only a thin shell of sapwood. Often the first evidence of a diseased interior is indicated by the appearance of the characteristic fruiting bodies of the fungus in some opening in the bark, or in some portion of the trunk that appears solid.

The Effect of the Mycelium upon the Wood. A small portion of decaying wood under the high power of the microscope may show the presence of the hyphæ to good effect. In a good mount, the hyphæ may be seen penetrating the woody tissues in all directions. Hard hickory or oak is changed to a soft non-resistant mass that may be crushed between the fingers without effort. This softening of the wood is due in part to the action of bacteria, at least where sufficient moisture is present; but doubtless also in large part of the digestive action of the hyphæ (Page 171).

The Fruiting Bodies. Some of the wood-destroying fungi are often referred to as *shelf fungi*, because of the striking shelf-like fruiting bodies of these species, which vary in size from thin ones

scarcely an inch across to those several inches thick and a foot or more in diameter. In some forms these structures are hard and resistant, and grow from year to year, producing spores each season; while others are less permanent and disappear in a few days or weeks. The fruiting bodies differ greatly in size, and general appearance. Some have fruiting bodies that appear as thin coatings, covering extensive areas of the bark, while others produce mushroom-like bodies that protrude from knot holes, or form clusters at the base of the affected tree.

Dissemination of Spores. The under surfaces of the fruiting bodies of many of these large fungi are either full of tiny holes, called *pores*, or bear numerous leaf-like *gills*, or *lamellae*, hanging in a vertical plane. In either form the total under-surface of the fruiting body is greatly increased. The spores are borne upon the surfaces of the gills, or within the pores, depending upon the type of fruiting body. Since the pores extend in a vertical direction and the gills hang in a vertical plane, the spores, when ripe, may readily escape from the fruiting bodies and be scattered broadcast by the wind. The fact that billions of spores are produced by these fungi makes it apparent why unprotected wounds upon trees are likely to become infected.

Care of Wounds. All wounds upon valuable trees should be given the greatest care in order to guard against the entrance of these injurious fungi. As has been pointed out (Page 133), branches should be cut off near the trunk so that the healing process may take place as rapidly as possible. This, however, is not sufficient; for, while the wood is growing over the wound, cracks frequently appear which provide suitable conditions for the growth of spores. To prevent this, some covering, such as paint, or one of the special preparations manufactured for this purpose, is necessary to keep out the spores until the bark has closed over the wound.

Effect of Broken Branches. Branches broken or cut off at a distance from the trunk are a serious menace to the life of the tree because it is impossible for the wound to heal over. The stub generally dies, and bacteria and fungi often find a suitable location for growth at its base and cause decay that generally extends into the

heart of the tree. (Fig. 70.) The stub later breaks off, leaving a permanent entrance for water and organisms which hasten the destruction of the wood on the interior. In thick woodlands small branches on the shaded trunks of trees die and, in a short time, break off. These leave small wounds, however, that soon dry out and generally heal over without becoming infected by fungi. (Page 132.)

EDIBLE MUSHROOMS

General Character. In general the large fungi, known as mushrooms (Figs. 109 and 110), are similar in structure to the tree-destroying types. The common field mushroom, which in warm, wet



FIG. 109. — SHAGGY MANE SHOWING STRUCTURAL CHARACTERS (Photograph furnished by W. B. McDougall)

weather often appears abundantly in pastures and lawns, is a good representative of this group. The mycelium of this fungus grows through the soil and utilizes the organic matter present there as its food supply. When mature, it gives rise to the fruiting bodies that appear above the surface and produce the spores. The presence of the mycelium in the soil is often not suspected until after a period of rains, when the fruiting bodies appear.

The edible mushrooms differ from many of the

wood-destroying forms in that the former are generally soft and readily decompose, while the fruiting bodies of the latter are often much harder and more resistant. There is, however, no hard and fast line separating those that grow upon wood from the edible types

common in the fields. Some species that grow upon trees are excellent food, as, for example, the *oyster mushroom*, while others that are found upon the ground are poisonous and even very deadly, as is the case with certain *amanitas*.

Edible and Poisonous Mushrooms. Many kinds of mushrooms are edible; in fact, a large majority of species that are tender enough may be eaten without danger. On the other hand,



FIG. 110. — MORELS, ONE OF THE EDIBLE SPECIES OF MUSHROOMS
(Original photograph)

a considerable number of species that, to the casual observer, are quite similar to the common edible forms, are extremely poisonous. In some of these, a piece no larger than a small marble may cause speedy death. The deadly forms, moreover, may grow in situations similar to those of the harmless ones, or even be scattered among them. The chief reason that more inexperienced people are not poisoned is that the dangerous species are in many localities comparatively rare.

Identification of Poisonous Mushrooms. There are no set rules for separating poisonous from edible mushrooms. Any test

that is held to be a certain guide in this respect is likely to do more harm than good. The only safe criterion is for the collector in the field to be as familiar with the edible forms of our common mushrooms as he is with any other species of plant used as food, and to discard all specimens of uncertain identity. An intelligent person, with the help of some good book upon edible mushrooms, may gain

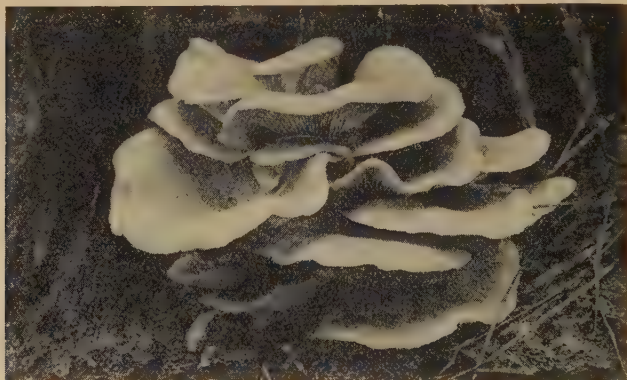


FIG. III. — OYSTER MUSHROOM, AN EDIBLE FORM THAT OFTEN GROWS IN LARGE NUMBERS UPON DEAD FOREST TREES
(Original photograph)

such familiarity in a short time. A person who is fond of these fungi and who wishes to collect them in the field certainly should make a careful study of the desirable types before trusting himself to gather specimens for table use. The reason that mushrooms in general look so much alike to the average person is not so much their actual similarity, as the lack of familiarity with the various species. Some of the common edible species — as the morels (Fig. 110) and the shaggy manes (Fig. 109) — are so easy to identify that there is no more danger in using them than in gathering and serving dandelion greens from the field. Others closely resemble deadly species, and should be identified beyond the possibility of error — or not eaten.

Saprophytes and Parasites. Fungi obtain their food from either dead or living materials. Field mushrooms, puffballs, molds,

and others, that live upon the dead substances are known as *saprophytes*. Wheat rust, smuts, some tree-destroying fungi, and many similar forms that obtain their food from living plants, are known as *parasites*.

These two groups cannot be separated from each other very definitely, for there are many intermediate forms that serve to connect the more typical representatives. Some forms, like the rusts, are always parasites; others, as the puffballs, never grow upon anything but dead materials; while still others, including certain wood-destroying species, may attack a living tree and remain growing upon it after death occurs. It is quite probable that the mycelium in some cases, at least, kills some of the tissues long before the host plant as a whole dies. With such, the fungus, although growing upon a living plant, is really more a saprophyte than otherwise in its habits.

Importance of Saprophytes. Saprophytic

forms of life are the organisms that, in general, attack our foods and cause the decomposition of various other organic materials, such as lumber and leather. They also produce the most far-reaching results in the soil by the reduction of plant and animal remains to substances that green plants may use in their growth processes. (Page 169.)



FIG. 112. — THE FLY MUSHROOM (*Amanita muscaria*)

One of the most poisonous mushrooms known. Photograph by E. T. Harper. (From Allen and Gilbert, page 81)

Importance of Parasites. Parasites, whether belonging to the fungi or to the bacteria, are also of the highest importance to man, in that they attack living things, both plants and animals, and either injure or kill them outright. In this group are found most of the organisms that cause disease. Parasitic bacteria and one-celled animals, known as *protozoans*, cause most of the diseases of man and other animals; parasitic fungi more generally infect plants.

SOME DISEASES OF PLANTS

WHEAT RUST

Injury Done by Wheat Rust. The wheat rust is the best known and most injurious of all wheat diseases. It attacks wheat, oats, and some other nearly related crop plants, and interferes with

the production of the kernels. The injury may vary from a comparatively small reduction in the weight of the grain in light attacks to total destruction in severe infections. Since these crop plants are so important economically, it is easily understood why this species of rust has excited widespread interest and received careful study



FIG. 113. — STAGES IN WHEAT RUST

Left — Black rust upon straw. *Center* — Red rust upon the blade. *Right* — Cluster-cup stage upon barberry leaves. (Original photograph)

on the part of those working with plant diseases.

Forms of Wheat Rust. The life history of wheat rust includes three very clearly defined and well-marked stages, namely, the *red rust*, the *black rust*, and the *stage upon the common barberry*. In the north central states, the red rust appears upon the blades

of growing wheat and nearly related plants, generally, early in the summer. The black rust, which follows this stage, is found upon the dry straws or stubble later in the season; and the barberry stage appears upon the leaves of barberry in the spring.

Red Rust. Production of Spores. The red rust stage is characterized by the abundance of reddish spores that form in elongated, bed-like clusters and break through the epidermis of the blades or sheaths. The elliptical spores are borne upon short stems from which they are easily blown by the wind to other host plants and so spread the rust with rapidity through a field of grain.

Scattering of Spores.

When the red spores from infected leaves reach other plants they germinate, if atmospheric conditions are favorable. The hyphæ arising from these spores enter the new host plants, and in a short time, often only a few days, the fungus becomes mature and produces its



FIG. 114. — *Left* — RED RUST SPORES SHOWING OCCURRENCE AND METHOD OF GERMINATION. *Right* — BLACK RUST SPORES, THEIR CHARACTER AND METHOD OF GERMINATION

(From Duggar, *Fungous Diseases of Plants*, Ginn and Company. By permission)

crop of spores, which likewise blow away and infect other host plants. Spores of this type seem to be relatively short lived and do not carry the rust through the winter, except possibly in the South where green host plants are found throughout the cold season.

Weather Conditions and Red Rust. Prolonged wet weather at the time when wheat is heading out, or a little later, often brings about conditions suitable for the rapid development and spread of red rust. In fact, abundant moisture is such a constant and apparently necessary accompaniment of serious rust infections that wet weather is not uncommonly supposed to be the direct cause of rust.

This, obviously, is not true. The rust plants always arise from spores, without which no infection from this fungus can occur.

Black Rust. After the red rust has disappeared and the straw or stubble is drying out, numerous beds of glossy, black spores appear upon the surface. These, which originate from the same mycelium that produced the red spores, constitute the black rust stage. The black or winter spores are two-celled structures with heavy, resistant walls, capable of withstanding unfavorable weather conditions better than the red rust spores. They are the resting spores of the wheat rust, and serve to carry the fungus over the winter. (Figs. 113 and 114.)

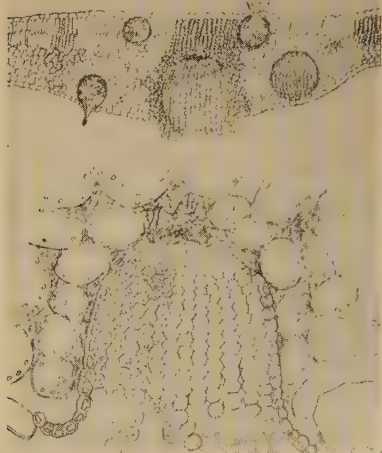


FIG. 115.—Above—A CROSS SECTION OF A BARBERRY LEAF SHOWING THE OCCURRENCE OF THE CLUSTER CUPS. Below—A SINGLE CLUSTER CUP HIGHLY MAGNIFIED

(From Duggar, *Fungous Diseases of Plants*, Ginn and Company. By permission)

In the spring the winter spores germinate by sending out short hyphæ upon which are borne several tiny spores. When these are carried to the common barberry, they infect the young leaves of this plant.

The Barberry Stage. Soon after the barberry leaves are infected with wheat rust, wart-like structures form upon the under surfaces. In these spots appear (Figs. 113 and 115) clusters of cup-like openings containing myriads of small spores. Because of these characteristic structures, this form of the wheat rust is known as the *cluster cup stage*. The spores from the barberry, carried by the wind to growing wheat or some other host, give rise to the red rust, and the cycle is complete.

The Control of Wheat Rust. This disease has proved most difficult to control. Many others, like potato scab, oat smut, brown

rot of fruits, and mildew of grapes, quite readily yield to treatment by sprays, or poisons applied otherwise; but these common methods of combating plant diseases have no effect on rust.

There is some hope that varieties of wheat may be developed and commonly grown that naturally resist rust, just as some of our horticultural plants are immune to certain plant diseases. However, the procedure that seems to be the most promising, at least so far as immediate results are concerned, consists in the *eradication of the common barberry*. Some have held that this action would not



Japanese Barberry

Common Barberry

FIG. 116. — CHARACTERS OF THE COMMON AND JAPANESE BARBERRIES (Original photograph)

necessarily do away with the rust, as the fungus may live through the winter and infect the growing wheat in the spring without the barberry's functioning as a host — at least in the warmer regions. Whether this is true or not, it seems that the eradication of the barberry is an advantageous step. There is no question but that the barberry rust is one of the normal stages in the life of the wheat rust, and the complete eradication of this shrub would doubtless be effective in materially checking this very destructive fungus.

The Common and Japanese Barberry Compared. A word concerning the barberries is not out of place here. There are in the central states two types of barberry used as ornamental shrubs: the common form with its several horticultural varieties, and the

Japanese barberry. This latter plant is in no way concerned with the wheat rust. As both barberries are beautiful ornamental shrubs, it is important to be able to distinguish the two. The common type is generally the much larger of the two plants, often growing eight or ten feet tall; while the Japanese seldom is much over four feet in height. The thorns of the larger plant are often branched, having three points; while those of the Japanese are generally unbranched. The common barberry bears its flowers in elongated clusters, while on the other plant they are borne singly or in pairs. (Fig. 116.)

OAT SMUT

Oat smut is a very destructive disease, often causing losses of from 10 per cent to 25 per cent of the crop where no precautions

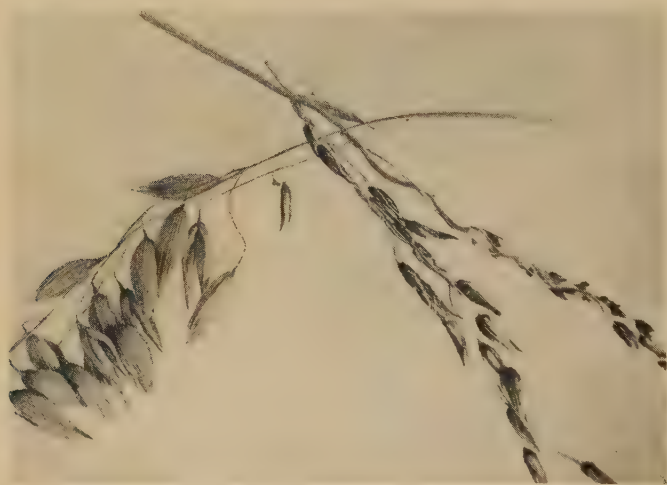


FIG. 117.—OAT SMUT

Left — Normal spikelets. *Right* — Infected spikelets. (Original photograph)

are taken against it. Fortunately, however, a very effective and inexpensive remedy for this fungus is known.

Life History of Oat Smut. The mycelium of this fungus

develops within the tissues of the host; and the spores are formed about the time the oat heads begin to appear. The fruiting bodies, which are really masses of black spores, are always found in the heads of oats, where they take the place of the kernels. Consequently, the smutted heads are very readily distinguished from those that are healthy. In some cases, however, where the plant is very badly injured, the diseased head may remain within the sheath and be hidden, and a field may be much more seriously affected than appears at first sight. (Fig. 117.)

The spores become scattered during the harvesting of the crop, or at the time of threshing, and reach the mature kernels of oats and adhere to them. About the time the grain germinates in the spring the smut spores produce hyphæ that infect the young oat plant. These hyphæ grow through the tissues while the oat plant is developing, and a crop of spores instead of kernels is produced.

Prevention of Oat Smut.

Since the smut spores are carried exclusively upon the surface of the kernels from one

crop of oats to the next, it is an easy matter to kill them and thus prevent the recurrence of the disease. This is usually done by treating the seed oats just before sowing with a weak solution of formalde-



FIG. 118. — CORN SMUT
Young fruiting body upon sweet corn.
(Original photograph)

hyde, and then exercising care to prevent other spores in old sacks or in a dirty drill from reaching the grain. Hot water may also be used, but this treatment is much harder to carry on successfully, because of the difficulty in maintaining the water at the temperature required.

POTATO SCAB

Another common disease with which almost everyone is familiar is potato scab. The presence of the disease is shown by the occurrence of the scabby surface of the tuber. (Fig. 119.) The scab

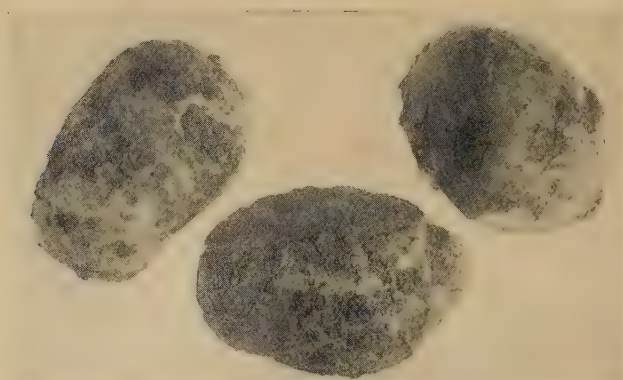


FIG. 119.—POTATO SCAB (Original photograph)

interferes materially with the sale of potatoes; and in serious infections, other organisms that bring about decay gain entrance.

The Infection of Potatoes. The organism that causes potato scab is somewhat obscure and not easy to find. It lives over winter, either upon the infected tubers or in the soil where the infected crop has grown, and apparently can remain alive in the soil for at least three years and still be able to cause infection, provided potatoes are again planted there in that time. In combating this disease, therefore, one must not only look after the seed potatoes to see that they are not scabby, but must ascertain also whether the soil where the crop is to be planted has grown infected potatoes recently.

The Prevention of Scab by Treatment of the Seed Potatoes. Seed potatoes may be readily freed from the organisms that cause scab by being soaked for a short time in a weak formaldehyde solution, in much the same way that oat smut is combated. This is



FIG. 120. — POTATO LEAF AFFECTED BY EARLY BLIGHT
(From Weed's *Farm Friends and Farm Foes*,
page 225)

sufficient to destroy organisms upon, or near, the surface and thus render them safe for planting. This treatment is inexpensive and, when used in connection with a clean soil, is very effective in preventing this disease.

DISEASES OF FRUITS AND VEGETABLES

There are a large number of fungi that grow upon fruit trees and garden plants, causing great losses every year. Among these affect-

ing our fruits may be mentioned brown rot of peaches and plums, black and bitter rots of apples, apple scab, and peach scab; in our



FIG. 121.—APPLES AFFECTED BY BITTER ROT

(From Weed's *Farm Friends and Farm Foes*, page 247)

gardens are found various blights, leaf spot diseases, wilts, mildews, and the like. Not infrequently a single fungus may cause the total loss of the crop, but fortunately means have been devised to control many of these diseases.

Spraying. The most effective means of control is the use of sprays. This practice is recognized as absolutely essential if a high type of product is to be obtained, wherever fruits and vegetables are raised on a commercial scale. Spraying is also the most effective means of controlling insect injuries in the orchard and garden; but the chemicals used for these pests gener-

ally are different from those used for fungi. Frequently, however, the two types of poison are combined in one solution and applied at the same time to serve the double purpose.

Bordeaux Mixture. The most important and effective fungicide spray is Bordeaux mixture, so named from the city in France near which it was first employed to prevent mildew of grapes. This spray consists of a mixture of slacked lime and copper sulphate dissolved in water. So generally is it now used, that it may be obtained at drug stores in small or large packages ready to be mixed with a given quantity of water and applied at once. Although some care

is necessary in order to apply the spray properly, yet the results are so satisfactory, that the cost and trouble attendant upon its application are scarcely to be considered.

YEASTS¹

The Nature of Yeasts. The simple, minute organisms known as yeasts constitute a group of plants of great economic importance. They are much simpler in structure than the molds and other fungi

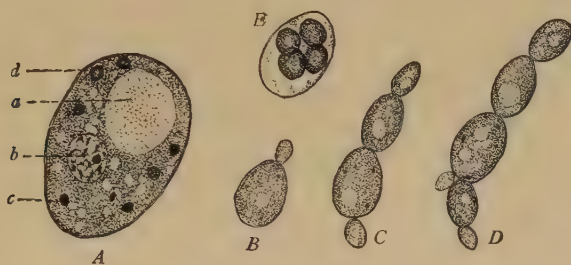


FIG. 122. — A YEAST

A, a single cell, killed and stained so as to show its parts; *a*, vacuole; *b*, nucleus; *c*, *d*, reserve food. *B*, the division of the cell by budding. *C*, *D*, chains or colonies, formed by the remaining together of the daughter cells after division. *E*, spores inside the wall of the mother cell. (From Allen and Gilbert's *Textbook of Botany*, page 33)

already studied. Instead of being made up of various parts, such as mycelium or well-defined fruiting bodies, each plant consists of a single cell.

The Structure of the Yeast Plant. The yeasts are so minute that their structure can be made out with difficulty, even by the use of the higher powers of the microscope. The common form used generally in making bread appears as colorless, oval cells filled with a slightly granular protoplasm within which frequently appears a more or less well-defined vacuole. (Fig. 122.) The nucleus is not

¹ *Bacteria, Yeasts, and Molds in the Home*, and *Microbiology*, are very valuable references for this work as well as for bacteria. See Bibliography.

easily seen. The plants vary considerably in size and in the way they are grouped—often occurring singly, but more frequently, especially if they are multiplying rapidly, in short chains of from two to four cells loosely attached. Even with the commercial yeast cakes, which are comparatively pure, other species of very different appearance from those described above are often present.



FIG. 123. — TEST FOR CARBON DIOXIDE

The left-hand tube contains clear lime water; the right-hand, lime water into which carbon dioxide has been passed. (Original photograph)

The Effects of Yeast Growth. Yeasts grow in sugary solutions, and when developing, generally bring about what is known as alcohol fermentation, in which the sugar is used up and alcohol and carbon dioxide are produced. The fermenting liquid acquires a sharp taste due to the alcohol in solution, and has a characteristic appearance due to the escape of bubbles of the carbon dioxide.

These results may be readily observed in a glass of cider or grape juice that has been kept in a warm atmosphere for a few days. Certain other substances also are produced, but generally in very much smaller amounts.

Reproduction in Yeasts. *Budding.* Yeasts multiply by a process known as *budding*. A mature cell forms a small wart-like protuberance at one end, which becomes filled with protoplasm from the parent plant and rapidly enlarges. In some types the cells thus formed remain attached, producing the short chains referred to above; in other cases they soon separate. Under favorable conditions this multiplication takes place with such rapidity that, in a few hours, immense numbers of plants are produced—sufficient, in fact, notwithstanding their minute size, to bring about far-reaching results.

Spores. Under certain conditions yeast plants produce spores, which appear as tiny spherical objects, from one to eight in a cell, and probably function as do the resting spores of the fungi already

discussed. This is not the only, or even the most important, means, however, by which our common yeasts are enabled to maintain themselves through periods not suitable for growth. In fact, spore formation seems to be rather infrequent in those with which we come into contact in the home.

Dry Yeast Cells. The protoplasm of yeasts, as well as that of many other low forms of life, is able to live without moisture for long periods and revive when moisture is again present. Yeast cells—at least with our common commercial forms—constitute in the dried condition the chief means by which these plants are carried through periods not suitable for growth. The dried plants, upon coming into a situation where moisture is abundant, very rapidly begin active growth.

Substances That Prevent Growth. Yeasts are frequently prevented from growing in a food material through the use of large quantities of sugar. Although sugar is food for yeasts, yet, if the solution is strong enough, these plants (as well as bacteria) are unable to develop in it. Consequently, preserves, if made properly, keep well even though but little attention is paid to canning them. Several other common substances which have a similar effect upon the growth of yeasts and bacteria will be discussed later in the study of bacteria.

Various poisonous chemicals kill yeasts or prevent their development. If a very small amount of formaldehyde is placed in a culture of yeast, the cells cease activity at once. Chemicals that act somewhat in this way, but are not so dangerous to human beings, are sometimes used to prevent yeast growth in sweet cider. The greatest care should be exercised in such practices,



FIG. 124. — CARBON DIOXIDE FROM GROWING YEAST

The left-hand tube contains actively growing yeast; the center, lime water into which carbon dioxide from the tube containing the yeast has been passed. The right-hand tube contains clear lime water for comparison. (Original photograph)

for there is a real danger that prolonged use in foods of amounts of chemicals sufficient to interfere with the growth of yeasts, may, in the end, be injurious to the human body.

Wild Yeasts. The species of yeasts that find their way through the air to injured fruits or to sugary fluids in the household, such as cider, or grape juice, are called *wild yeasts*, to distinguish them from those forms generally employed in bread making and the brewing industries, which are spoken of as *cultivated yeasts*. The chief difference between the two groups is that the first is composed of an indefinite number of species, capable of producing a variety of changes in food substances, while the second has come into existence through a selection of comparatively few forms adapted to bring about certain desired effects. With the cultivated yeasts, therefore, much more uniform results are likely to be obtained than by the use of the wild forms.

Poisonous Substances Produced by Wild Yeasts. While the most typical products of yeast growth are carbon dioxide and ethyl alcohol, frequently small amounts of other substances are formed by certain species and related organisms that may be not only undesirable, but positively dangerous. This fact may explain, in part at least, the sometimes deadly effects of the so-called "home brew," which is often produced through the activities of wild yeasts.

The Foods Used by Yeasts. Yeasts, like all other forms of life, must have a constant supply of food while they are active. They utilize this food just as do higher organisms, to supply energy for the life processes, and to repair or build up their own bodies. Often yeasts are said to need only sugar in some form as a food, but this is hardly true. Sugar is by far the most important food used by yeasts, but there must always be sufficient proteins present to provide materials for the building up of the protoplasm during active growth. The amount of this nutrient necessary, however, is exceedingly small; and it is practically always present in sufficient amounts in the various substances in which yeasts ordinarily grow.

Glucose and other simple sugars are practically always present in fruit juices, and are the forms generally used by yeasts, although

some others may be utilized. *Cane sugar*, for example, is often broken down, but before it is used within the yeast cells, it is converted into glucose and a similar sugar through the action of an enzyme produced by the cells. *Starch* does not seem to be utilized by our common yeasts as food, but certain bacteria that occur frequently in connection with yeasts, may transform some of the starch to sugar, after which fermentation may take place, and the result may seem to be due to the direct action of yeast upon starch.

Respiration in Yeasts. *Aerobic*.

Ordinary, or aerobic, respiration occurs in yeasts to some extent when sufficient oxygen is present. (Review the section upon respiration, Chap. IV, with care.) The re-

sult of this ordinary respiration is the formation of those products that represent the complete breaking down of organic materials, such as carbon dioxide and water. No alcohol is formed. If this type of respiration were the rule, yeasts would be of practically no economic importance, but the predominating type is that which occurs without the presence of free oxygen (at least with the cultivated types) and forms the important products *alcohol* and *carbon dioxide*.

Anaerobic. As has been noted, the presence of sufficient oxygen makes it possible for the organic food substance, such as sugar, to be reduced to carbon dioxide and water, thereby releasing all of the

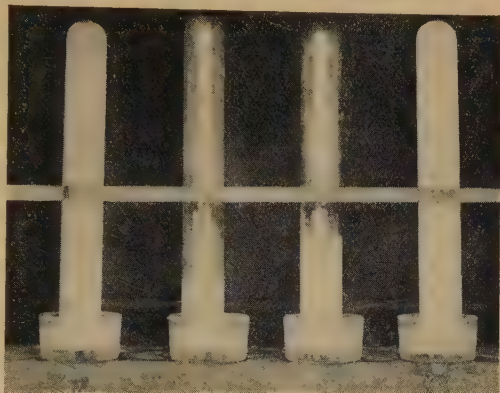


FIG. 125.—FOOD OF YEASTS

1. Tube contains yeast and water. 2. Yeast and glucose solution. 3. Yeast and cane sugar solution. 4. Yeast and starch mixed with water. The amount of carbon dioxide gas in the tubes indicates the amount of growth of the yeast plants. The tubes were allowed to stand in a warm room for several hours to give the plants time to grow. (Original)

available energy. When oxygen is absent, or essentially so, as is the case in anaerobic respiration, the reduction of the food substance may still take place, but there are these important differences: only a comparatively small part of the energy is released, and the products formed are of an intermediate character, such as alcohol and other complex substances that still contain energy.

This is exactly what takes place with yeasts in general, and also with a large number of other lower forms of plants, chiefly bacteria, that are able to live without the presence of free oxygen. Such organisms are active in the breaking down of organic substances into the simpler, yet still complex, products characteristic of decomposing matter.

The Production of Alcohol by Yeasts. In anaerobic respiration, sugar, often in the form of glucose, passes into the protoplasm of the yeast cells, and becomes broken down through the activity of an enzyme into alcohol and carbon dioxide. The sugar molecule is reduced without the addition of free oxygen, and consequently, may take place out of contact with air. If the glucose were completely oxidized by aerobic respiration, much oxygen from the air would be used, and the resulting products would be carbon dioxide and water, but no alcohol.

The Fermentation of Fruit Juices. Fruit juices always contain considerable quantities of sugar, and consequently are excellent media for the growth of yeasts. With apple cider, fermentative changes begin in warm weather very soon after the juice leaves the press; bubbles of carbon dioxide appear, and the liquid acquires a sharp, biting taste, due to the presence of alcohol. The yeasts that so speedily bring about these changes are generally of the wild types, which find their way to the juice through the air, or from the apples used in making the cider. Under suitable conditions for the growth of the plants, the action continues until a considerable percentage of alcohol is produced.

Vinegar Production. The fermentation of apple cider is of only minor importance in itself, but indirectly it is of considerable commercial value, for the hard cider, as the fermented product is called, is in turn acted upon by certain organisms, known as

acetic acid or *vinegar bacteria*. These transform the alcohol present into acetic acid, the characteristic substance in vinegar and often form slimy masses on the vinegar, which are generally referred to as the "mother." Much commercial vinegar is now produced through purely chemical processes; but the higher grades are made from fruit juices in the manner described.

Uses of Yeast in Bread Making. The most common use of yeast in the home is in the production of bread. In this process, it is the carbon dioxide, rather than the alcohol, formed through the activity of the yeasts, that is desired. The dough made from wheat flour, which is most generally used for bread, is a sticky, elastic mass; and if baked without the use of yeast, or some substitute such as baking powder, the product would be hard and more or less unsuitable for food. Yeast gives this important food its lightness and wholesomeness.

Carbon Dioxide in Dough. Although there are many variations in the practice of bread making which need not concern us here, in general, a very large number of yeast cells — derived from dry cakes by soaking in warm water, or from compressed yeast — are thoroughly mixed with the dough and allowed to grow for a time at suitable temperatures. The cells develop rapidly in all parts of the dough, and the resulting bubbles of carbon dioxide formed throughout the substance do not easily escape because of the character of the dough. As a result the whole mass increases in volume, or rises.

Effect of Heat on Gas in Dough. When the loaves are ready for the oven, each contains vast numbers of bubbles of carbon dioxide gas held together in the elastic dough. In a hot oven, the gas bubbles expand rapidly and as a result the whole loaf shows a marked increase in size. As soon as the temperature reaches a certain point, the gluten to which the elasticity of the dough is due hardens, or coagulates, and the loaf, which thereby becomes firm, is able to maintain its shape.

Effect of Heat upon the Alcohol. While these changes are occurring, the alcohol, which vaporizes very readily, is driven off, together with a considerable amount of the water vapor. The

yeast cells, which are of course destroyed, remain in the bread; but they are in no way harmful — in fact, they are now looked upon with considerable favor as a food substance.

Compressed Yeast. Compressed yeast, now quite commonly used in localities where it can easily be obtained, consists essentially of a quantity of moist, active yeast cells, together with some starch and other substances. When it is used in bread making, the growth of the yeast begins at once upon being mixed with the dough; consequently, the bread rises in a comparatively short time.

The yeasts furnished in this form are obtained either from the vats where alcoholic products are made, or from special solutions which are allowed to ferment for this definite purpose. Since compressed yeast is moist, it must be kept cool to prevent the rapid development of the yeast cells. Under the best conditions the cakes keep only a short time.

Advantages of Compressed Yeast. Compressed yeast is much more certain in its action than other types employed in the making of bread. This is because it is relatively pure, and consists, at most, of a very few species of organisms, whose characteristics are well known; whereas a large number of forms, many wild and of uncertain value, were found in much of the yeast used a generation ago. This purity is possible because in growing this yeast care is exercised to obtain very active forms and keep out undesirable ones. Another advantage in the use of compressed yeast is found in the rapidity of its action. When the raising of bread is much retarded, other organisms are likely to develop in the dough in sufficient numbers to cause souring and other objectionable results.

Dry Yeast Cakes. Dry yeast cakes are very generally used in many localities in the making of bread. Yeast in such a form is very convenient; the cakes are easy to handle, and may be kept for a much longer time than compressed yeast. The cells in the dry cakes are in the resting stages, most of them in the dried condition, although some may be in the form of spores. Whatever is their condition in the dry cake, considerable time is required to bring them to the actively growing stage, and consequently the dry cakes are generally soaked for a time in warm water before being placed in

the thin dough, known as the sponge, in which they are allowed to grow over night at a suitable temperature for development.

The comparatively long time that the plants must be given to develop sometimes results in trouble, due to injurious organisms, chiefly bacteria, that are often present in yeast cakes. This is true if the dough is kept too warm, and again if it is kept too cool, so that the growth of the plants is very slow. Probably not all of these forms are objectionable; for some of the characteristic flavors of bread made by certain methods may be due—in part at least—to the activities of bacteria that develop under special conditions.

Temperature for Bread Raising. It is desirable, whichever kind of yeast cakes is used, that during the development of the plants the dough be kept at a temperature suitable for the growth of the yeasts, and still low enough to retard the action of the other organisms that are likely to produce undesirable results. The temperature that gives the best results is from 75° F. to 90° F. During cold weather, a warmer temperature, even up to 95° F. may be used with good results; while in the hot season, a temperature of 70° F. is quite satisfactory.

Flavor and Texture Due to Yeast. The yeast in the bread not only raises the dough, but also gives desirable flavors, and suitable texture to the bread. The flavor and texture are governed both by the type of yeast used and by the rate of growth of the plants. Consequently, it is just as important to look carefully after the temperature which determines largely the rate of growth of the plants, and thus influences the flavor and texture of the bread, as it is to select a suitable type of yeast in the first place. The control of the rate of growth of the yeast is one of the important details in the art of bread making, and the ability to do this is generally acquired through long experience.

The Production of Dry Yeast Cakes. A word concerning the making of dry yeast cakes will serve to give a better understanding of this product. The material is prepared by using as a starter some cultivated yeast which is mixed with starch and other substances, together with a sufficient amount of water to give a mush-

like consistency to the mixture. The cells are allowed to grow in this until multitudes are formed throughout the mass. The batter is then made into the form of cakes, or sometimes left as a coarse powder, and dried. During the drying the temperature is kept low enough so that the cells are not destroyed by the heat, but are gradually brought to the resting stage in which they may live for a considerable length of time. Eventually, of course, the dried cells will die, the cakes become worthless, and fresh cakes must be obtained.

Yeast Brews. In former years, brewing yeast was a common procedure in the home, and even yet it is practiced there to some extent. In this process, a solution known as the brew is prepared, in which the yeast plants will grow readily. Often this is a mixture of thoroughly boiled potatoes, water, and some hops and other substances. When the solution is cool, a small quantity of yeast from some source is added and allowed to grow for a few days. The mixture will then contain large numbers of yeast cells and may be used in the making of bread.

This method is unreliable except in the hands of one who has had much experience in its use. The fact that the brew must stand for several days before being used in the bread offers abundant opportunity for contamination by a variety of organisms that often produce undesirable results.

Yeasts and Fruit Canning. Yeasts frequently cause trouble in the canning of fruit. Canned fruit that has been acted upon by yeast generally acquires a sharp taste due to alcohol, and bubbles of carbon dioxide appear. Other organisms may produce these substances, but not so often as yeasts. When bacteria cause the spoiling of foods, obnoxious odors and tastes are likely to result. Fruit affected by yeasts, may, unless the action has proceeded too far, be restored to approximately its original condition by heating, which drives off most of the alcohol. Such fruit often may be re-canned with but little injury to its quality. Methods of preventing injury to canned fruit by yeasts will be discussed in connection with the treatment of bacteria.

CHAPTER VIII

BACTERIA

GENERAL NATURE OF BACTERIA

Bacteria are very minute, one-celled plants that are extremely abundant. Yet they are seldom seen except by those who are making a study of them, for they are so small that even with the highest powers of the microscope they can be seen easily only when they are stained in a way to make them visible. They are known to most people through the effects they produce, which are, in many cases, very striking and very far-reaching in importance.

Bacteria and Yeasts Compared. 1. Bacteria are similar to yeasts in their general food relations. Both depend for their materials for growth and for their supply of energy almost entirely upon substances produced directly, or indirectly, by green plants. There is this difference, however, that the most abundant food used by yeast is sugar, while proteins are the most characteristic substances used by bacteria, although the other nutrients are also utilized. Alcohol is the most striking product of yeasts, while acids and a host of other complex organic substances of varied character are formed by bacteria. 2. Bacteria are somewhat simpler in structure than yeasts, and generally much smaller. 3. The most marked and constant difference between them is in the method of multiplication. There is no stage in the development of bacteria that resembles the budding of yeasts. Bacteria increase by a process in which the parent cells divide into two parts of approximately equal size. These daughter cells rapidly enlarge under suitable conditions, and again division occurs.

The Importance of Bacteria. The great importance of bacteria will at once become apparent when some of the far-reaching results of their activities are pointed out. There are certain out-

standing effects that may be mentioned. 1. Bacteria are known to be the cause of a large number of our most fatal diseases which affect man or the lower animals. 2. The preservation of our foods,

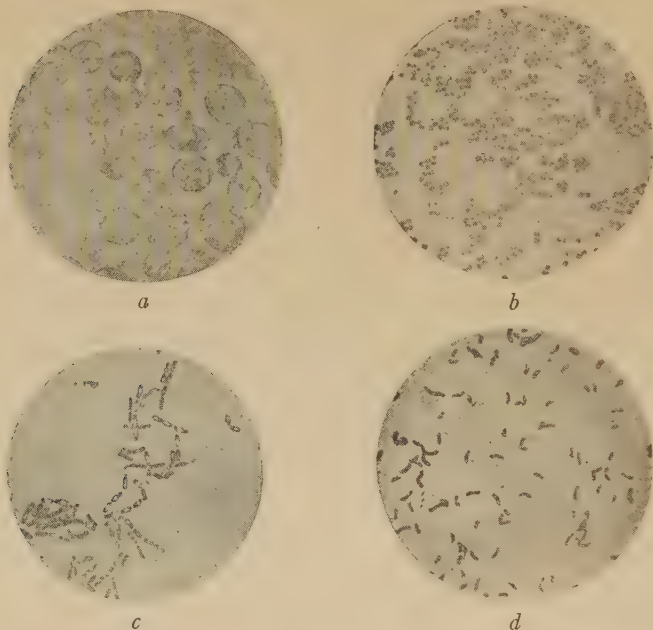


FIG. 126. — *a*, YEAST PLANTS, SOME OF THEM BUDDING; *b*, MICROCOCCI (singular, micrococcus) FROM THE AIR; *c*, *BACILLUS SUBTILIS*, SHOWING INTERNAL SPORE-FORMATION; *d*, BACILLI (singular, bacillus) OF ASIATIC CHOLERA, WITH MOTILE FLAGELLA

Photomicrographs $\times 740$. After Günther. (From Stevens' *Introduction to Botany*, page 257)

whether by refrigeration, canning, or otherwise, is successful only when these organisms, together with yeasts, and molds to some extent, are prevented from developing, or are killed outright. 3. The fertility of the soil is largely dependent upon the activities of certain groups of bacteria that make it possible to maintain the supply of nitrogen and other elements which are absolutely necessary for the growth of green plants. 4. The bacteria are the most im-

portant agents in the general processes of decay whereby the complex organic remains on the earth are reduced to the simple substances suitable for the growth of green plants, as described in Chapter VI. 5. Bacteria are also of importance in the production of certain desirable changes in food substances, such as the souring of milk, the formation of the acetic acid of vinegar, and the ripening of cream.

Occurrence of Bacteria. Bacteria are the most abundant organisms on the face of the earth. They are always present in vast numbers wherever organic matter exists, and wherever temperature and moisture conditions are suitable for their development. On the surface and within the upper layers of the soil where most of the plant and animal remains are found, bacteria exist in vast numbers. Rivers and smaller streams, as well as small bodies of water fed from surface drainage, are generally well supplied with these organisms. Large lakes, or arms of the sea for that matter, are by no means free from them. The air, especially when practically free of dust, as after heavy rains, contains but few bacteria. At other times when clouds of dry particles from organic materials, or from the soil, are blown about, myriads of bacteria are to be found. In and about human habitations, where food is abundant and conditions for development are generally satisfactory, bacteria are to be found practically everywhere unless special precautions are taken to prevent their growth.

Bacteria for Laboratory Study. It is generally easy to obtain bacteria for class use. Almost any sort of decaying organic material may be used for this purpose. Coarsely ground peas or

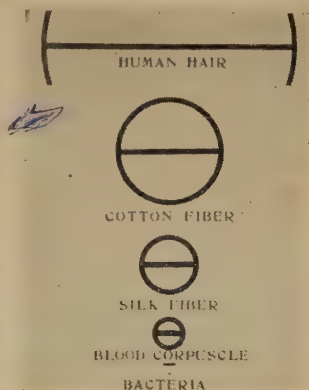


FIG. 127.—THE SIZE OF BACTERIA IN COMPARISON WITH SOME COMMON OBJECTS

All of the objects represented above were magnified to the same degree. The larger of the two bacteria represented is one of the medium sized germs; the smaller, one of the most minute that is visible under the highest powers of the microscope. (Original)

beans, or scraps of raw lean beef placed in a small quantity of water and kept in a warm room, are excellent sources. Small particles of the substance that collects between the teeth are interesting because of the various types of organisms found there. Probably the best method to obtain bacteria for continued observation in the laboratory, however, is by means of the so-called hay culture.

Hay Culture. Hay culture is made by soaking a handful of small pieces of clean timothy hay in a quart or so of water, and allowing the mixture to stand for a few days in a warm room. As the organic extracts from the hay provide an abundance of suitable food, many microscopic organisms develop with surprising rapidity, serving to give an excellent idea of bacteria and other low forms in their active stages.

Change in Appearance of Culture. When first made, the liquid is quite clear; but it rapidly begins to cloud up, and in a day or two becomes quite murky. If a drop of the murky fluid is examined under the high power of the microscope, it will be seen to contain immense numbers of bacteria. These gain access to the culture from the hay, or possibly from the dust in the air, or from the water; at any rate, food and other conditions for growth are favorable and development takes place rapidly.

One-celled Animals in Hay Culture. As the culture becomes older, an interesting succession of different organisms appears. At first the bacteria are very abundant; but they gradually become less so until the water may become almost clear again. While this is taking place, a large number of species of minute, one-celled animals appear and then pass away, one form replacing another. At one time a given species will be very abundant, and in a day or two it will disappear and another will become dominant. And so the succession goes on. (Chap. XII.)

The Structure of Bacteria. Bacteria are generally so small that little can be made out concerning the internal structures, even with a good microscope. There is a definite *cell wall* that surrounds the living substance; and, in some species, there is an external gelatinous covering that causes the bacteria to hang together in slimy masses, like those forming the "mother" in vinegar, and

those that collect on the surface of a hay culture. In some species there are very slender protoplasmic strands known as *flagella*, which occur upon various portions of the cells. These flagella, which are exceedingly minute and difficult to see, are concerned with the movements of these organisms through the water.

Species of Bacteria. There are many kinds of bacteria; but they are generally very difficult to identify with the aid of the microscope alone because of their small size and the absence of well-marked distinguishing characters. Bacteriologists rely largely upon the habits of growth and upon certain staining methods to determine the species; but even then, identification is sometimes a difficult task.

Types of Bacterial Cells.

Three groups of typical bacteria are generally recognized: the *spherical*, the *rod-shaped*, and the *spiral* forms. It is not difficult to find representatives of each of these types in a single mount taken from a hay culture that has been allowed to stand open in the laboratory a few days.

Generally, however, one type predominates at a given time.

The spherical forms may occur

singly, in pairs, in chain-like strands, or clumped in irregular masses.

The rod-shaped bacteria may appear singly in the culture, but more frequently they form chains made up of from two to many cells. The spiral forms most frequently occur as single cells.

Motility of Bacteria. Some species can move about in the water in which they are growing, while others can not. Those upon whose bodies flagella are well developed are able to progress with apparent rapidity, as can be seen under the high power of the microscope. However, in order to get a correct idea of their true

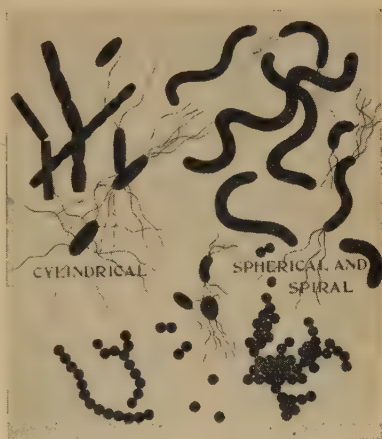


FIG. 128. — TYPES OF BACTERIA

(From a wall chart by the author)

rate of movement, one must remember that the speed at which they cross the field of vision is magnified and made to appear much greater than it really is. Currents in the liquid in which the bacteria are developing frequently play an important part in the distribution of all forms, whether motile or non-motile.

Multiplication of Bacteria. Multiplication of bacteria takes place by a process known as *fission*. In this process, the protoplasm of the mature cell divides in the middle and cell walls grow in be-

tween the two portions, thus completing the division. In some cases the cells elongate before dividing, and in others the division takes place, first, after which the cells grow to the normal size. The most important fact concerning the multiplication of bacteria is the rate at which new cells are formed.

Rate of Multiplication.

Bacteria increase, under favorable conditions, at a rate astounding to observers who have not studied these organisms.

In some forms, the length of a generation — that is, the time from one cell division until the daughter cells are ready to

divide again — may consist of but twenty or thirty minutes. Under favorable conditions of food supply, temperature, and the other factors in growth, therefore, a bacterium may give rise to twenty-four generations in twelve hours.

At such a rate the number of bacteria that would be produced in twelve hours, considering each generation twice as numerous as the one immediately preceding, mounts well into the millions. If the multiplication proceeds unchecked for a longer time, the figures representing the number of individuals very soon become so large

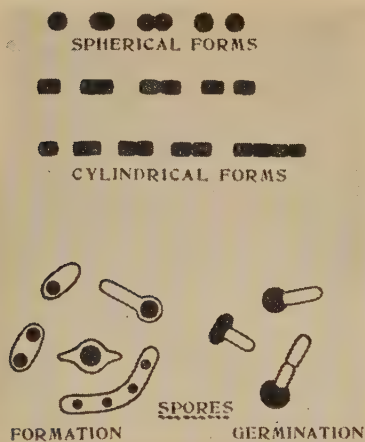


FIG. 129. — MULTIPLICATION OF BACTERIA, SPORE FORMATION, AND GERMINATION (From a wall chart by the author)

that they cease to mean anything to us. It should be said, however, that this rate of increase never continues for any great length of time, because of the unfavorable conditions that are bound to enter, such as failure of food supply and the formation of injurious substances that check the growth of bacteria.

Spore Formation. Certain species of bacteria produce spores. These are formed from the protoplasm within the cells and soon become surrounded by definite and resistant cell walls. Since often but a single spore forms in a cell, this process is not a means of multiplying the number of bacteria. The value of the spores to the species is found in their great resistance to injurious conditions that would check the development of the growing cells or even kill them outright. It is due to the spores or to the dry resting cells which occur frequently with the bacteria, that these forms of life are able to pass through times unfavorable for growth and again develop when suitable conditions appear.

Resistance of Spores. Spores are remarkably resistant to the agents — such as heat, drying, and certain chemicals — usually employed to destroy or prevent bacteria from developing. Although growing bacteria are readily killed by water held at a temperature far below boiling, yet certain spores are able to endure water at the boiling point for hours and still develop. They are also very difficult to kill by drying; spores of some species are able to live for a long time in dust and other dry materials. They show a similar resistance to chemicals and other destructive agents, probably due to their compact protoplasm and the character of their walls.

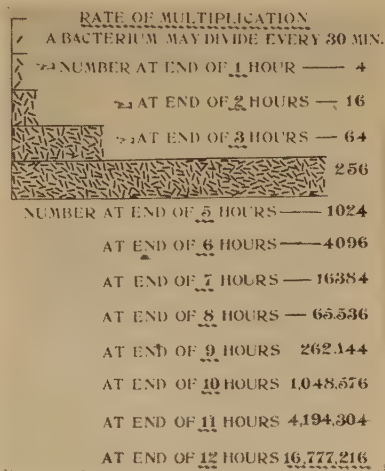


FIG. 130. — MULTIPLICATION OF BACTERIA (From a wall chart by the author)

Food of Bacteria. Although carbohydrates and a wide range of other substances are used to a greater or less extent, the most characteristic food of bacteria, in general, consists of proteins. Since these nutrients are widely distributed in organic materials, bacteria are able to utilize practically all forms of organic matter. As has been said, these organisms are the most important of all those concerned in the general breaking down of the complex organic materials to simple compounds.

Amount of Food Needed for Bacterial Growth. The quantity of food absolutely necessary for bacteria is, in some cases, exceedingly small. Certain species can multiply in ordinary distilled water, deriving their nourishment from the mere traces of food found there. The maximum amount that may be used can scarcely be stated definitely. Most bacteria are checked in their development by the products of their own activity. In sour milk, for example, the bacteria that form the acid cease their activity when this product reaches a concentration of one per cent or a little more. If the acid is neutralized, the bacteria will again become active. Sometimes a soluble food substance that is very concentrated, sugar, for example, will check their growth through osmotic action. (See section on osmosis.)

Utilization of Food by Bacteria. Bacteria use food for the same general purposes as do animals and higher plants; namely, to produce energy, and to furnish materials out of which new living substance may be formed. There are often important differences, however, in the manner in which the food is utilized, and in the wastes produced. Animals, in obtaining their energy, as a rule, oxidize the food substances to *carbon dioxide and water* and certain comparatively *simple nitrogenous waste substances*. Bacteria of the aerobic type, that is, those that utilize free oxygen in their respiration, bring about changes similar to these; but many kinds behave like the yeasts and produce *alcohol*, as described in the preceding chapter, and *intermediate substances*, such as *acids* and a very large variety of other compounds.

Putrefaction and Decay. From the foregoing discussion, it is easy to understand the difference between putrefaction and decay

as the terms are often applied to organic materials. In the former, the changes which are brought about by bacteria and other organisms do not go to completion, and, consequently, complex substances having disagreeable odors are formed; in the latter, the actions go to completion with the result that carbon dioxide, water, and other simple substances appear. Both processes are generally concerned in the reduction of complex, organic materials as they exist in nature.

The early changes that occur are not necessarily harmful. In fact, the flavors of certain foods, such as of butter and of fresh meats, are greatly improved in this way. The changes that occur later and give rise to substances having disagreeable odors and flavors, and sometimes to poisons, are the ones generally referred to by the term putrefaction.

It is important to see clearly that the process known as decay really is made up of a long series of complex changes that follow each other in succession and result, finally, in the complete oxidation of the organic matter.

Moisture and Bacterial Growth. More moisture is essential to the growth of bacteria than to other non-green plants save the yeasts. If the medium in which they are developing dries out, or if water is prevented from entering the cells, the bacteria cease their activities and enter the resting stages until conditions are again favorable. Many forms, notably a number of important disease germs, seem unable to survive long in the dry state. The spreading of infectious diseases through the air on the dust particles is not nearly so frequent as was once supposed. But bacteria that produce spores are able to resist drying for a long time, even for years, and then under favorable conditions renew their growth.

CONTROL OF BACTERIAL DEVELOPMENT

Dried Foods. Drying as a method of preserving foods has been practiced for centuries. All sorts of edible materials are kept in this way — fruits, vegetables, meats, fish, and, in recent years, even milk and eggs. The success of the practice depends upon the fact that the organisms of decay, the most important of which are

bacteria, cannot develop in the absence of considerable quantities of water. In past years the moisture was generally removed by exposing the food substances to the sun in the open air, but more recently appliances have come into use by which the water may be rapidly evaporated from the materials, thus giving a better product than that formerly obtained.

Temperature and Bacterial Development. Various species of bacteria differ greatly as to the temperatures at which they may develop. Some forms are known to multiply slowly in water not far above the freezing point; while others have been found apparently growing actively in hot springs, where the temperature is scalding. These forms are, however, very exceptional and are of only passing interest to us. All of the common forms, such as those involved in decay, in the decomposition of foods, and in human diseases grow best at temperatures ranging from 75° F. to 100° F. or slightly above.

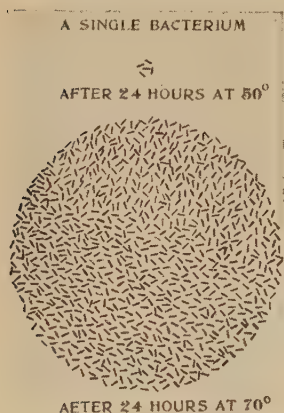


FIG. 131. — RELATION OF TEMPERATURE TO BACTERIAL DEVELOPMENT

(From a wall chart taken from *Bacteria, Yeasts, and Molds in the Home* by Conn, published by Ginn and Company, New York. By permission)

Temperature and Rate of Growth. It is important to understand the effect which increasing the temperature has upon the rate of growth of bacteria. A typical form may multiply not at all at 40° F., but as the temperature is raised to 50° F., activity begins to be apparent and division takes place slowly. As the heat is raised to 60° F., 70° F., 80° F., and higher, the development proceeds at

a faster and faster rate, until a point is reached, say at 95° F., at which the most rapid growth takes place. As the heat becomes more intense, the activity decreases gradually—in some species rapidly, in others more slowly—until a point is reached at which development ceases. Finally at a temperature somewhat higher death ensues.

The effect of a varying temperature upon the development of organisms is of general application to living things, and provides one of the most important ways by which man is able to control the development, not only of lower forms but also of higher plants as well.

High Temperatures and Sterilization. High temperatures are very deadly to bacteria in all stages, whether they are actively growing or in the form of spores. Heat whether applied through steam, hot water, the open flame, or in some other way, is the best means known for the destruction of bacteria and related organisms. In fact, complete sterilization, which means the destruction of all the organisms in the substances sterilized, is seldom accomplished in ordinary practices except through the application of heat. (Fig. 132.)

Moist Heat Most Effective. Heat is far more effective as a destructive agent when applied in connection with an abundance of moisture than when but little water is present. Water at 150° F. to 180° F. is deadly to actively growing bacteria in a few minutes, and at the boiling point, even resistant spores are killed by a prolonged exposure; although in some cases this may require several hours.

Use of the Autoclave. A more effective means of sterilization than merely boiling in the open air is found in the use of the *autoclave*. This apparatus consists essentially of a strong metal container closed by an air-tight lid, in which materials to be sterilized may be subjected to steam under pressure. The enclosed steam may be raised to 250° F. or more, at which temperature the most resistant spores are killed in a few minutes.

Dry Heat as a Sterilizing Agent. Dry heat, such as is obtained in an ordinary oven, is much less effective than moist heat. Consequently much higher temperatures must be employed when this method is used. Glassware, such as dishes and test tubes, may be thoroughly sterilized in this way by gradually bringing the temperature up to 350° F. or higher, and maintaining it there for not less than one hour.

Open Flame and Sterilization. The most rapid and certain

means of sterilization is the open flame, or in other words, the burning of infected materials. This procedure is obviously of limited application; yet on the whole it is of great value, especially where wastes from the sick are to be destroyed, or discarded clothing is to be disposed of. In all such cases as these burning should be employed.

Pasteurization. Pasteurization of milk, or other fluids where the process is sometimes used, consists in the application of a moderate degree of heat for the purpose of destroying the active organisms present. It differs from sterilization by boiling because of the much lower temperatures employed, and consequently in being less thorough in the destruction of germs. Temperatures of 140° F. to 145° F. applied for twenty minutes are often used in the pasteurization of milk. This degree of heat is sufficient to destroy most of the actively growing bacteria, but has little effect upon those in the resting stages.

Pasteurization and Disease Germs. Since disease germs generally do not produce spores, pasteurization is of great advantage in securing the safety of milk used raw for human consumption. This is especially true in regard to young children; for it is a well-recognized fact that polluted milk, when fed to babies, causes much sickness and many deaths, especially during the summer months. Records from institutions where large numbers of babies are kept show very clearly that simply pasteurizing the milk without changing the diet in any other way brings about a remarkable decrease in the death rate from intestinal troubles.

Effect upon Keeping Milk. Another advantage of this treatment of milk is the marked improvement in the keeping power of this product. Milk properly pasteurized will remain sweet for a considerable time if stored in a cool place, but gradually changes take place similar to those that occur in the untreated product. This results from the presence of bacteria that were able to resist the moderate temperature employed.

Effect upon Milk as Food. The effect of pasteurization upon the quality of milk seems to be slight. It is doubtful whether any changes occur which are detrimental to its use as a food for

infants. Boiling markedly alters milk, and temperatures near the boiling point have a corresponding effect. It may be said with certainty that the increase of safety from the standpoint of disease germs far outweighs any detrimental changes produced in the quality of the milk by the moderate degree of heat used in pasteurization.

Canning. The most common method of keeping perishable foods, in both homes and factories, is canning. This process consists essentially: 1. In the destruction of all organisms present in the food substance and, 2. In the prevention of the entrance of others from the outside. These results are accomplished through sterilization by heat, after which the products are sealed in air-tight cans.

Several important factors are involved in the canning of fruits and vegetables.

1. Extreme cleanliness should be practiced with the jars and other containers, and with the fruit or vegetable to be preserved. Dirt, or even the dust that may settle upon the material, often contains resistant spores that are difficult to kill, and if these are not removed by careful washing with clean water, the likelihood of loss of the canned product will be greatly increased.

2. If the best results are to be obtained, only fresh, high class materials should be used. If changes due to decay have already begun in the fruit or vegetable to be canned, it is obvious that the final product cannot be of high grade. At best, much of the flavor of many fresh fruits and vegetables disappears through the process of sterilization; consequently, in order to make up for this unavoidable loss, only the best stock should be used if satisfactory results are to be obtained.

3. Thorough sterilization is an absolute necessity, especially in all cases where no preservatives, such as a large amount of sugar or perhaps, acids, are used. No amount of care in other ways can make up for carelessness in regard to sterilization.

Earlier Method of Canning. In former years the canning of fruits or vegetables not difficult to keep was done by boiling the material in an open kettle and then sealing it in air-tight cans while it was still boiling hot. This was not always sufficient to

insure complete sterilization, however, and in more recent years another and very efficient process, known as the cold pack method, has come into general use in the home, especially with vegetables that are difficult to preserve.

Cold Pack Method. The cold pack method is very simple and, as ordinarily recommended, there is but little difficulty in using it in the average kitchen. The vegetable to be canned is cleaned with care, then scalded for a few minutes, after which it is immersed in cold water, and finally placed in clean glass jars. These are then filled with water to which a little salt is often added, and the rubbers and lids are placed in position and partly tightened.

The cans thus prepared are then immersed well beneath the surface of water in a suitable container, and boiled for a comparatively long period. With vegetables such as corn, likely to contain resistant bacteria or spores, it is recommended that boiling be continued for at least three hours. In other cases where considerable acid is present and where there are no special difficulties to overcome, thorough sterilization may be accomplished in much less time.

During the heating, it is important that the cans be kept well covered and that the water be kept constantly at the boiling point. It should always be kept in mind that the heat must penetrate the food substance in the cans and that if the water is allowed to boil away until the tops of the jars are exposed, portions of the contents are likely to escape thorough sterilization.

Upon removal of the cans from the boiling water, the lids are immediately fastened so as to be air tight, thus effectually preventing the entrance of bacteria from the dust or other outside sources.

Commercial Canning. In commercial canning factories, sterilization is accomplished most generally in large boilers or vats into which steam under pressure is passed. (Other methods of heating the food products are sometimes used.) The higher temperature thus obtained is very effective as a sterilizing agent, as was pointed out in a preceding section.

The Effect of Low Temperatures upon Bacteria. Cold as a means of killing bacteria has but little value. Although tempera-

tures near and below freezing entirely prevent the development of bacteria, those even very much lower are not effective in destroying these organisms. Diphtheria and typhoid germs have apparently been uninjured by long periods of exposure to liquid air and liquid hydrogen.

Bacteria in Ice. Ice from contaminated sources is not purified by freezing, and it may still contain bacteria, although probably a smaller number than were in the water from which it was formed. When water contaminated with typhoid germs freezes, a considerable proportion of these bacteria are killed outright, and those remaining alive gradually decrease in number. These facts, however, should not be taken as evidence that ice from water contaminated with dangerous bacteria is safe for human consumption.

Refrigeration. Early Practices. The employment of low temperatures for the preservation of fresh foods, such as meats and milk, has long been used in the home. In earlier days the cool cellar or deep well as a means of maintaining a low temperature during the hot season, was looked upon as a great convenience, and today in many communities is still largely in use. Somewhat later, in regions where there is much freezing weather during the winter, ice was cut from ponds and lakes and stored in great quantities to be used during the hot weather. Within the present generation this practice, though by no means discontinued, has ceased to be of such great commercial importance.

Cold Storage Plants. Through the discoveries and developments that have made it possible to produce low temperatures artificially, modern systems of refrigeration have appeared in recent years, and now constitute tremendously important industries. To-day almost every city of any size has an ice plant which supplies ice for families and shops. The larger cities have extensive cold storage plants, suitable for the preservation of vast quantities of fruits, vegetables, meats, eggs, and, in fact, all sorts of perishable products. These establishments, together with refrigerator cars and ships, have become a necessity in connection with the traffic in fresh foods of all kinds.

Prevention of Decay through Low Temperatures. The

principle underlying refrigeration, obviously, is the effect of moderately low temperatures in preventing, or at least in slowing down the development of bacteria and other organisms that bring about decomposition. Cold also checks certain chemical changes that naturally occur in fruits and other foods which, if allowed to proceed, soon result in deterioration. It should be kept clearly in mind that the process of refrigeration, as ordinarily applied, does not necessarily kill or even injure the organisms in the stored materials; in fact, the cold seems to preserve the bacteria in excellent condition for growth when at a suitable temperature.

Temperature Used. The average small refrigerator in the home where but comparatively small amounts of ice are used, seldom reduces the temperature much, if any, below 45° F., during hot weather. In the cold storage plants, however, much lower temperatures are generally employed. It is customary to keep many food products such as eggs, fruits, and numerous others, but slightly above the freezing point. In other cases, notably with fish and poultry, the products are frozen and kept in that state for considerable periods. Although many foods will keep a long time in cold storage, yet it appears that when thawed out there is a marked tendency for rapid decomposition to set in.

Sunlight and Disinfection. Sunlight has a well-marked and often deadly effect upon bacteria in general, as well as upon other micro-organisms. Many of these forms in the active, growing stages are killed by a very short exposure, sometimes of only a few minutes, to the *direct rays* of the sun. Bacteria, lodged in dust, and exposed in other ways in the open are, without doubt, destroyed in great numbers during clear bright weather through sunlight and drying. Diffuse light, such as is ordinarily found in our houses, exercises a hindering effect upon bacterial development, but is not in any sense deadly. The common practice of placing clothing, tinware, and other household furnishings out in the direct sunlight is doubtless of some value from the standpoint of sterilization; but this method should not be relied upon to get rid of bacteria.

It should always be remembered that it is only the direct rays of the sun that are deadly, and that consequently only the exposed

surfaces are acted upon in an effective manner. The inner portions of such articles as clothing are protected by the outside layers; obviously any bacteria that may be on the interior escape the full force of the sunlight.

Rays Deadly to Bacteria. The deadly effects of sunlight are not due to the heat that accompanies it, but to the light rays themselves. The various colors of which white light is composed differ greatly in their action upon bacteria. Those at the red end of the spectrum have little or no effect; those near the violet portion are the most deadly, and it is to these that the sunlight owes its germicidal powers. It is an interesting fact that ordinary window glass acts as a screen to certain of the deadly rays, other than the blue and violet, and consequently light that passes through it is not so effective in destroying bacteria as when there is no glass intervening.

Definitions. Those chemical substances that are deadly to bacteria and are employed in the destruction of these organisms are usually called *disinfectants*. Those that are more or less poisonous and are used merely to prevent the growth, but are not effective in killing bacteria outright, are called *antiseptics*. Others that are considered harmless when taken into the human body, and still are effective in hindering growth are referred to as *preservatives*. It should be kept clearly in mind that there are no hard and fast lines separating these three classes, and that a single substance when used in different concentrations may correctly be included in more than one group. The term *germicide* is often used to refer to substances deadly to disease germs.

Disinfectants and Antiseptics. There is no need of trying to draw a definite line between these two groups. The very large number of chemicals used to combat bacteria and similar organisms are of all degrees of effectiveness ranging from the very deadly to those that merely hinder growth. Again, the same substance when used in strong solution may be a powerful disinfectant, while in dilute condition it has very feeble germicidal power and simply prevents growth. Corrosive sublimate well illustrates this character. Some other common disinfectants behave in much the same way.

Formaldehyde. Its Nature. Formaldehyde is a gas, poisonous and of a penetrating odor, and readily soluble in water. The solution as ordinarily sold in drug stores contains from 35 per cent to 40 per cent of the gas. At moderate temperatures, or more rapidly when heat is applied, the gas is given off into the surround-

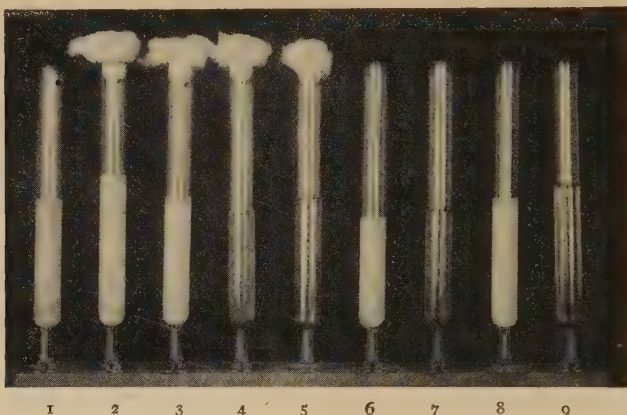


FIG. 132.—THE EFFECT OF VARIOUS AGENTS UPON THE GROWTH OF BACTERIA IN CLEAR HAY INFUSION MADE FROM TIMOTHY HAY. See text. The cloudy appearance indicates bacterial growth. All of the tubes were kept in a warm room for twenty-four hours after they were prepared.

1. Untreated. 2. Heated to 60°C . for 10 minutes. 3. Heated to 80°C . for 1 minute. 4. Heated to 80°C . for 1 minute on three successive days. 5. Boiled for a few minutes. 6. A few crystals of table salt added. 7. One-third of the volume of liquid is table salt. 8. A small amount of sugar is present. 9. One-third of the volume is sugar. See text and laboratory guide for discussion. (Original)

ing air. Consequently, unless the solution is kept with care its strength is likely to vary considerably. For disinfecting purposes, formaldehyde may be obtained in solid form, in which it is less offensive and less difficult to handle; or with special apparatus it may be produced from wood alcohol.

Uses of Formaldehyde. Formaldehyde is not suitable for all types of disinfection, but it is widely used for the fumigation of houses after infectious diseases; as a treatment for certain plant

diseases, notably potato scab and oat smut, as described in Chapter VII; and as a preservative for animal and plant tissues in museums or biological laboratories. Formerly it was used to some extent as a preservative for milk, and in very small quantities it was extremely effective for this purpose, but its definitely poisonous nature has caused this use of the substance to be abandoned. Formaldehyde is not suitable for use upon the human body either in cleansing wounds or in disinfecting the surface of the skin.

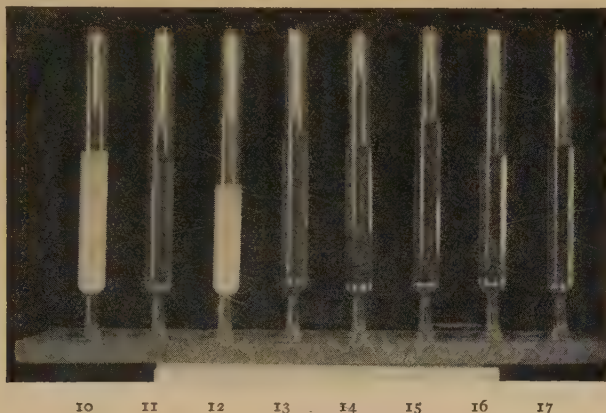


FIG. 133.—EFFECT OF VARIOUS AGENTS UPON BACTERIAL DEVELOPMENT (continued)

10. Small amount (a drop or two) of vinegar present. 11. One-third strong clear vinegar. 12. Small amount of borax present. 13. One-sixth of the volume borax. 14. One drop of weak solution of formaldehyde present. 15. One drop of commercial formaldehyde present. 16. One drop of weak solution of mercuric chloride present. 17. One drop of strong solution of mercuric chloride present. See text for discussion. (Original)

Formaldehyde in the Disinfection of Buildings. Formaldehyde is much used in disinfecting buildings because it is quite effective in destroying germs, and it has the great advantage of being harmless to fabrics. Such is not the case with sulphur fumes formerly used very generally after sickness.

If the formaldehyde is to be effective, the air in the room must

be moist, the temperature should be at least 60° F., and the room should be sealed so that the gas may act for a number of hours. Care must be taken that the amount of gas used is sufficient for thorough disinfection. Authorities affirm that if a 40 per cent solution is used and completely evaporated, twelve ounces are required for every 1000 cubic feet of space to be disinfected.

Carbolic Acid. Carbolic acid is one of the oldest and most widely-used disinfectants. If a five per cent solution is used it is quite effective in destroying the growing bacteria; even spores may be killed by sufficiently long exposure. The power of this substance to kill germs—and the same is true of many other disinfectants—is likely to be overestimated by those who have not studied the subject carefully. A five per cent solution of carbolic acid requires twenty-four hours to kill all the bacteria in sputum from a tuberculous patient.

It is important to remember that chemical substances used as germicides must, in most cases, be used in liberal quantities and be allowed to act for prolonged periods of time to insure complete sterilization.

Slacked Lime. Slacked lime, or calcium hydroxide, as it is known chemically, is one of the cheapest and most effective disinfectants known. When a large amount of germicide is needed, as in the treatment of privy vaults and the like, this substance is most satisfactory. The small cost of the chemical makes it practicable to use large amounts of the disinfectant, a practice which, as stated above, is a very important factor in obtaining complete sterilization.

It has been shown that a 20 per cent solution of slacked lime mixed with an equal quantity of wastes from a typhoid patient destroys all germs within an hour. It should be remembered that either quicklime or water-slacked lime, upon standing in contact with air for a long time, absorbs carbon dioxide and changes to calcium carbonate, a substance of no germicidal power.

Other Substances Used for Chemical Disinfection. Of the large number of other substances of value used as germicides, only a few can be mentioned. *Corrosive sublimate*, known chemically as

mercuric chloride, is often used in solution of 1: 1,000 as a wash, either for the surface of the body, or for floors and wood work. In this strength, it is very effective unless albuminous substances are present, a condition that greatly decreases its power. The *fumes of burning sulphur* (sulphur dioxide) which are used to some extent as a gaseous disinfectant, are effective provided the air is moist and warm, and sufficient sulphur is used. Its bleaching power, however, is a great drawback. *Chlorine*, either from bleaching powder, or in the form of a liquid, is effective in the purification of drinking water where but small amounts of foreign matter are present. Among other germicides may be mentioned *ethyl alcohol*, which is not a very strong germicide although it is often used upon open sores; *silver nitrate*, expensive but very effective, and of such a nature that it may be employed upon mucous surfaces such as the eye; *iodine*, a strong germicide used often upon the skin; and a large number of coal tar products, related to carbolic acid, that are sold under various trade names such as *lysol*, *creolin*, and *cresol*.

Preservatives. An ideal preservative would prevent the development of bacteria and other related organisms, and would not injure the food in any way, or have poisonous effects upon the human body either immediately or after long use. It is doubtful whether any substance entirely comes up to this standard. Long use has shown that some, like *sugar* and *salt* — important food materials in themselves — are not harmful to the body, but these materially alter the products preserved in them. Some substances, as formaldehyde, for example, are extremely effective in preventing bacterial development, even when used in minute quantities, but are now generally condemned as dangerous to the consumer. Between these two groups there are a large number of chemical substances such as *borax* and *benzoic acid*, used extensively in food industries, that are effective when used in small quantities and alter the product only in a minor way so far as its general nature is concerned.

It is scarcely possible as yet to give a final statement of the ultimate effects upon the consumers of a long continued use of these

substances. During recent years high authorities upon food chemistry have come to exactly opposite conclusions concerning the poisonous nature of a number of them.

Chemical Preservatives in the Home. The following facts should be kept clearly in mind by those who are tempted to use chemicals sold under trade names to preserve canned corn or other products in the home. The protoplasm of the organisms that cause decomposition is certainly not very different from that within the cells of the human body; consequently, a chemical substance that in minute amounts is capable of preventing the development of bacteria in a can of vegetables should certainly be seriously considered as to its possible effects upon the cells of the human body. The greatest care should be exercised. Moreover, with the modern methods of canning in the home, there is no need at all of resorting to chemical preservatives.

Sugar and Salt as Preservatives. These substances, obviously, are not poisons and yet they have power to prevent the growth of bacteria and other organisms. Both are generally used in very strong solutions, and when thus used seem to act osmotically, reducing the quantity of water in the bacterial cells until growth is prevented. In the salting of fish or lean meat, sufficient water is extracted from the cells to form a solution with the salt, and the tissue becomes much drier and firmer. (Page 102.)

When sugar is used in the making of preserves the fruit is very likely to decrease in size and become much harder. This hardening is due to the loss of water, which passes out into the sugar solution. Quinces and certain plums when preserved in concentrated syrup sometimes become crinkled and tough because of these osmotic effects.

Vinegar as a Preservative. Vinegar, another harmless preservative commonly used in the home as well as in various commercial food industries, owes its preserving power to its acid nature. Spices, which are often used in connection with vinegar in the production of pickles of various sorts, are generally mildly antiseptic and probably aid in some degree in checking the development of destructive organisms. It will be useful to keep in mind

that acids very often hinder the growth of many of the common bacteria.

Kraut. The effect of acid in inhibiting the growth of bacteria has given rise to some interesting practices of preserving food substances other than through the use of vinegar. A notable example of this is sauerkraut which is made by packing chopped cabbage, together with a considerable amount of salt in a jar or other suitable receptacle, out of free contact with the air. Fermentations produced by a number of types of organisms in the substances give rise to acids which act as preservatives.

Silage. The preservation of green corn in the silos on the stock farms is another case where acid, produced by bacteria, doubtless plays an important rôle. Here the green corn is chopped up and packed in a specially prepared compartment out of free contact with the air, and the fermentations that occur result in the preservation of the material in a suitable condition for stock food.

Other Preservatives. There are other preservatives that may be mentioned in passing, which are used quite commonly in the homes in some communities. *Wood smoke* owes its antiseptic character to certain substances produced in the burning of wood and which in considerable quantity are poisonous. These substances are found in smoked meat or fish only in the minutest quantities, however, and there is no evidence that food thus treated is harmful to the consumer. Another preservative quite commonly used in the home, especially in the smaller towns and cities, is *water glass*. This is effective in preserving eggs in a fairly fresh condition for several months. Usually the eggs are immersed in a solution of one part of water glass to ten of water. This method serves very well for a time, but after nine or ten months, eggs preserved in this way show considerable deterioration.

DISTRIBUTION OF BACTERIA IN NATURE

Bacteria in the Air. The number of bacteria in still air is not nearly so great as one might suppose, judging from their abundance almost everywhere in the surface layers of the soil, or wherever

organic matter is found. Quiet air is often practically free from these organisms; in fact, in a room in which the air has remained undisturbed for a time, there is but little danger of contamination from this source. This is readily understood when one considers that bacteria seldom if ever float free in the air, and that they are carried, practically always, upon dust particles, which settle

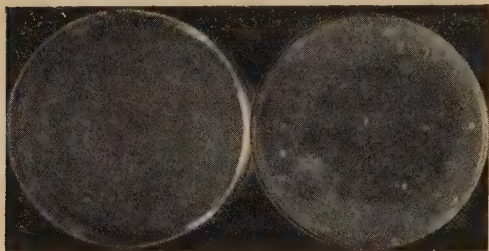


FIG. 134. — BACTERIA IN DUST

The petri dishes contain nutrient gelatin upon which bacteria grow readily. The small light colored dots are colonies of bacteria.

Left — Dish opened for one minute in a quiet room where the dust has been allowed to settle over night. *Right* — Dish opened for one minute in a room where a class was moving about. After exposure the dishes were kept in a warm oven for forty-eight hours. (Original photograph)

rapidly when currents of air are absent. The fact that these organisms are rarely blown from moist surfaces, even by strong drafts, serves to reduce the bacterial content of the air.

Avoidance of Dust. From the standpoint of sanitation, the facts bearing upon the presence of bacteria in the air are of great importance.

In the home, in the hospital, in establishments concerned with the handling of certain foods, such as milk, or in any other place where the presence of these organisms is especially undesirable, care should be taken to avoid dust. In laboratories, where great precautions against contamination from bacteria are necessary, special rooms are arranged for this purpose. In the home, a moist cloth or an oil mop which catches and holds most of the dirt is much more desirable than the dry cloth or brush that simply stirs up the dust.

The greatest advantage of the modern *vacuum cleaners* is that they remove a large part of the dust from the room, which the ordinary broom does not do. Polished floors which may be wiped up frequently with a moist mop, and rugs that may be readily removed to the open air and freed from much of their dust, are, from the sani-

tary point of view, greatly superior to carpets which in former years were firmly tacked to the floors, and served well to hold the dust that was stirred up anew at every successive sweeping.

Kinds of Organisms in Air. The kinds of organisms occurring in the air vary considerably in different situations. Yeasts and molds are quite generally distributed and contaminate food whenever exposed. Certain types of living bacteria, such as the hay bacillus, are very common in the air. This is due, in part at least, to their high resistance to drying.

Disease Bacteria in Air. A consideration of great importance is the fact that the germs of human diseases are generally not present in the air except under certain conditions. The scarcity of living disease bacteria in dry air is explained by the facts that in the active stages many such germs are easily killed by drying and other influences, and that only a few of them produce resistant spores. Bacteria are also scarce in sewer air doubtless because of the absence of strong drafts and dust in such surroundings.

Bacteria in the Soil. The surface layers of soil generally contain vast numbers of bacteria as well as related organisms of many types. These vary from the highly beneficial forms, such as the ones concerned with the fertility of the soil, to those that are extremely dangerous to human life, such as typhoid and tetanus germs. The continual supply of organic matter that finds its way into the upper layers of the soil, and the moisture conditions favorable for bacterial growth, are the chief factors responsible for the extreme abundance of micro-organisms near the surface.

Disease Germs in the Soil. The possible occurrence in the soil of human disease germs is a fact of great importance. The spores of *anthrax*, a dangerous disease of cattle as well as of man, apparently may remain in the soil in the living state for years. The germs of *tetanus*, or lockjaw, are of frequent occurrence in cultivated soils, in street dust, and in or near stables. The bacteria of *typhoid fever* and certain other human diseases may be present in situations directly infected by patients, and may become a real source of danger when occurring, for example, in the water supply or in vegetables eaten in the uncooked state.

Bacteria in Water. *Surface water.* Water from different sources varies greatly in bacterial content. It is obvious that ordinary surface waters, coming into contact as they do with the decomposing organic materials in the upper layers of the soil, must contain vast numbers of organisms. This is especially true where

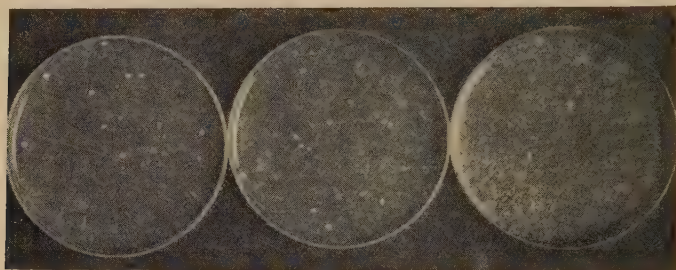


FIG. 135.—BACTERIA IN WATER

Each dish contains nutrient gelatin and 1/100cc of water. *Left*—Well water. *Center*—Cistern water. *Right*—Surface water. The light colored spots are colonies of bacteria. (Original photograph)

the water is flowing and carries much sediment rich in organic remains. Water that comes from a great depth under the ground, such as that obtained from wells and springs, if not polluted from the surface ordinarily contains very few bacteria.

Cistern water. It would seem that cistern water should contain small numbers of bacteria, since it is derived from rain. Such, however, is generally not the case; for organisms gain entrance from the dust particles of the air, from roofs upon which the rain falls, and from organic materials that collect in spouts and in the cistern itself.

Lake and river water. Water in large lakes, far removed from the contaminating influence of sewage and from the sediment of rivers, is likely to be comparatively free from dangerous organisms. On the other hand, water from rivers fed chiefly from the surface, and consequently carrying more or less sediment, is often well supplied with bacteria.

Kinds of Bacteria in Water. The kinds of bacteria occurring in water are numerous. In fact, practically any species, harmless

or otherwise, may be present at times. The vast majority of organisms ordinarily appearing in water consists in those forms commonly found upon the surface of the earth. These, in general, are concerned with the decompositions that are occurring upon the soil at all times and are harmless species. The bacteria of the greatest interest to us are those causing human diseases, which, far too often, are present in water.

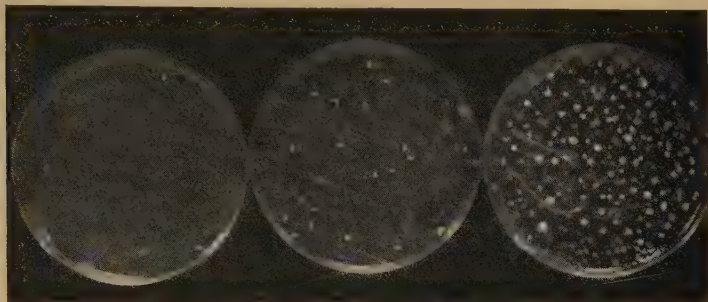


FIG. 136.—BACTERIA IN MILK

Left—Dish contains $1/100$ cc of fresh milk. *Center*—Dish contains $1/100$ cc of the same sample after it had stood for several hours at 70° C. *Right*—Dish contains $1/1000$ cc of very sour milk. The dishes which contain nutrient agar were incubated after the milk was added. See text and laboratory manual (Bennett) for discussion. (Original photograph)

Danger from Polluted Water. Of all food substances that may be contaminated with disease germs, drinking water is probably the most dangerous, because water is used in large quantities just as it comes from the well or faucet, while most other food materials are cooked, and thus are effectively sterilized. Milk and many green vegetables, which are used in the uncooked condition, are also dangerous from the standpoint of disease transmission. These will be discussed in connection with typhoid fever. (Page 258.)

The Contamination of Water. The dangerous qualities of water used for human consumption are due almost entirely to the presence of disease germs. Sometimes surface water contains the eggs of intestinal parasites, such as various species of worms. Water may also be unpalatable or possess peculiar characteristics due to

the presence of certain minerals; or it may contain poisonous chemicals, such as some lead compounds. All of these last-named types of contamination are comparatively rare. The great source of danger and the one considered with the utmost care relative to public water supplies is the possible presence of disease bacteria. Every year many millions of dollars are spent in removing them.

Typhoid Germs and Water. The germs most likely to cause trouble in the water supply are those capable of entering the human system by way of the digestive tract. Of these, the most important are the typhoid bacteria. Destructive epidemics of typhoid arising from a contaminated water supply formerly were of frequent occurrence all over the country; and even now, such outbreaks appear from time to time. The care exercised today, however, in relation to the source and purification of the water supply has done much to remove the danger from this cause. In small towns and in rural districts where the source of water for the household is the old-fashioned dug well, or the spring, so situated as to be open to surface contamination, outbreaks of typhoid still occur frequently.

Entrance of Disease Germs into Water Supplies. The dangerous organisms referred to above reach the water supply through surface drainage. The germs from the human patient may reach the soil through the careless disposal of intestinal wastes or otherwise, and may easily be carried considerable distances and gain entrance to the water supply. This is especially true when water is obtained from dug wells that are not very carefully located and which are not constructed to prevent the entrance of surface water.

Drainage into Wells. Even when the mouth of the dug well is considerably higher than the immediate surroundings, there is always danger if a source of pollution is anywhere near. Decayed roots of trees, the burrows of animals, or loose layers of soil may act as passageways for contaminating surface water. Where the surface is practically level, water in the upper layers of the soil naturally drains towards such an opening in the ground as a well; a well that receives a considerable amount of surface water often shows the effect of a short rainy spell by filling up quite promptly,

sometimes nearly to the surface. Such a well is always questionable, especially if it is in a thickly inhabited locality where human disease germs are likely to find their way to the soil.

Natural Purification of Water. Water that stands for a period of time sufficient for the sediment to settle loses many of its bacteria. This is shown clearly in deep lakes where the water becomes clear and contains but few organisms. Sunlight and the oxygen of the air may serve to decrease the bacterial content of water considerably at times; but sedimentation alone is sufficient to account for the reduction in numbers of bacteria in streams polluted by sewage. Surface water that percolates many feet of soil to the deeper strata is generally quite free from organisms, as is shown by the character of water from deep wells situated upon high ground, and from springs that are so located as to avoid pollution from the surface of the soil. But it should be remembered that clear water is by no means necessarily free from dangerous germs.

Sterilization of Water by Heat. In the home, the most satisfactory method of purifying water of a questionable nature is by boiling. No matter what disease germs may be present, the heating of the water to the boiling point for a short time is certain to remove all danger from this source, if subsequent pollution does not take place after it is cooled. The most inconvenient aspects of this practice, at least in the rural home, is the cooling of the water which, in warm weather, practically requires the use of ice.

The dissolved air is driven off when water is boiled, which changes its character somewhat when used for drinking purposes; but, on the whole, the change is a trivial matter compared to the increased safety resulting from the destruction of the dangerous germs. If there is any question as to the safety of water, it is always wise to boil that used for drinking purposes unless the danger is removed in some other way.

Sand and Gravel Filters. The purification of water by filtration through such substances as sand and gravel has been practiced for a long time. If applied with care, such filtration results in clarifying the water through the removal of the sediment and, consequently, in bringing about a reduction in the bacterial content.

This process, however, is now looked upon as being insufficient to insure any great degree of safety when the water is polluted with dangerous germs. Water that is perfectly clear and sparkling may still contain enough bacteria to be very dangerous. Usually some chemical treatment is employed after the removal of the sediment, in order to make the water safe for drinking purposes.

Small Porcelain Filters. The small filters on the market which are made of unglazed porcelain or some related material through which the water is forced, are not to be depended upon as an adequate means for the purification of water. They serve to take out the sediment, and, when clean, may remove many of the bacteria; but very soon they become much less efficient, and unless looked after carefully and cleaned frequently, they are practically useless.

Chemical Purification of Water. Alum. The very turbid waters of the central portions of the United States are now often clarified by the use of such chemicals as alum or ferric sulphate. When alum is added to muddy water it reacts on certain dissolved substances present and a flocculent, or curd-like, precipitate is formed that entangles the fine particles of sediment and carries them down. This sediment may then be removed with ease through filtration. This method is quite efficient also in removing bacteria. It is said that ninety-seven per cent or more of the organisms may be removed in this way.

Chlorine as a Disinfectant for Water. Chlorine, in some form, is the most common as well as the most efficient chemical now in use in this country for the destruction of bacteria in water supplies. This substance was, and still is, obtained to a considerable extent from bleaching powder, a product formed through the action of chlorine gas upon slacked lime. More recently liquefied chlorine has come into wide use for this purpose. Free chlorine, in the extremely dilute solution that is sufficient to dispose effectively of the bacteria in the water, seems to have no injurious effect upon the human body.

CHAPTER IX

DISEASE

BACTERIA AND DISEASE ¹

Early Ideas of the Cause of Disease. In early times and almost up to the present, very little was known concerning the cause of disease. Even the best educated people held to theories that now seem absurd. Probably the most general explanation offered was that demons or evil spirits somehow gained entrance to the body and thereby caused the trouble. Literature reflected this idea for twenty centuries or more. Even now in unenlightened countries, the belief in demons still prevails.

Early Treatments. Since evil spirits were looked upon as the cause of disease, it followed that treatment should in some way induce or compel the spirit to leave the body of the patient. Consequently, charms and sacrifices were resorted to, and we are told that sometimes the patient was beaten, not to punish him, but rather to compel the evil spirit to leave.

As knowledge of the human body increased, other theories of the cause of disease were advanced; and we find in the literature of past centuries a number of peculiar and even fantastic beliefs which did not point towards the truth. As a consequence, all sorts of practices arose, such as bleeding the patient for certain ailments and administering almost unthinkable concoctions as medicine. Such beliefs and practices prevailed within a half century ago.

The Work of Louis Pasteur. The discoveries that finally led to an understanding of the true cause of many diseases were made by Louis Pasteur, a Frenchman, who was born in 1822 and died in 1895. (Frontispiece.) The researches of this scientist,

¹ Authoritative discussions of many of the topics under this heading may be found in Jordan's *General Bacteriology*. See Bibliography.

one of the greatest of all time, also laid the basis for the scientific study of bacteria and kindred organisms. This epoch-making work probably has had a more far-reaching effect upon human welfare than any other series of discoveries in all the history of science.

Before the experiments of Pasteur and his co-workers, the theory of "*spontaneous generation*" was generally accepted. According to this belief, bacteria, yeasts, protozoans, and other microscopic organisms were supposed to *arise spontaneously from decomposing organic substances*. In the early days of the biological sciences, flies and even some of the larger animals likewise were supposed to originate in this way. The discoveries of Pasteur and his followers demonstrated beyond a doubt that *microscopic organisms do not arise from decomposing matter*, but gain entrance to such materials from without and *cause the decompositions*. This important work was extremely suggestive of the true nature and cause of disease.

In 1876, Koch, a German scientist, following the lead of Pasteur, proved conclusively that *anthrax*, a serious disease of cattle and other domestic animals as well as of man, *is caused by a living microscopic organism*. Working upon this and other known facts as a basis, Pasteur devised a vaccination treatment that was tested out on a large scale and was shown to be a very effective preventive measure against this disease. He also made remarkable discoveries relative to the prevention of the dreaded *rabies*, or *hydrophobia*, and perfected the method used at the present time for its control. Likewise, he devised a means by which a serious silkworm disease of southern France could be prevented. These discoveries opened up a very attractive field for investigation, and definitely pointed the way to the control of human diseases in general. Other scientists followed the lead of Pasteur and, during the latter half of the nineteenth century, they demonstrated conclusively that many human diseases are caused by living organisms, and that in numerous cases they may be controlled by applying the principles discovered by this great scientist and his co-workers. The general fact established by these investigators — namely, *that many diseases are caused by living organisms* — is the fundamental idea in the "Germ Theory of Disease."

Importance of the Germ Theory. The importance of the discovery that living organisms are the cause of many diseases can scarcely be overestimated. Modern sanitary and public health measures, as well as many practices for the control of contagious diseases, rest firmly upon the conviction that all diseases of this type are connected, directly or indirectly, with the development of germs within the body.

Control of Diseases Where the Cause Is Not Known. Such diseases as measles and scarlet fever,¹ the causes of which are still unknown, are controlled by the same public health measures as are employed to prevent those that are known to be caused by specific germs as, for example, diphtheria and typhoid. So general is the belief in the germinal cause of contagious disease, that immediately following the appearance of a strange ailment, definite search is made by health authorities for the causative organism. Whether the germ is found or not, possible means for its dissemination are carefully investigated. Until the cause of the disease is ascertained, the medical profession must work more or less in the dark regarding its control.

Certain Diseases Not Caused by Germs. It should be stated in this connection that certain types of diseases are probably not closely related to germs or even connected with them in any way. Among these may be mentioned, by way of illustration, conditions arising from malnutrition and the effects of certain foods and poisons upon the body. Statements of this sort must be made with caution, however; for in recent years, it has been shown that some diseases that seemed very far removed from any possible bacterial cause are definitely connected with these organisms. Examples of this are found in some types of rheumatism, and some forms of insanity, such as the softening of the brain. Even some nervous troubles are now known to be allied with the growth of certain germs in focal abscesses, such as are found upon the roots of dead teeth and in the tonsils.

Types of Disease Germs. A large proportion of the organisms

¹ Recent evidence (1924) seems to indicate that scarlet fever, like many other diseases, is caused by a specific germ.

that produce disease may be grouped in one of two classes: 1. *Pathogenic*, or disease-producing, *bacteria*, and 2. *Pathogenic protozoans*, which are one-celled animals. Another distinct group of organisms that sometimes cause serious disturbances in the human body is composed of the parasites referred to, in general, as *worms*. These are scarcely looked upon as disease germs, yet they should be mentioned in any general discussion of the organisms that cause disease. It may be said, in passing, that the eggs or larvae of these parasites are prevented from entering the body by much the same methods as are employed against disease germs — that is, through general cleanliness with regard to food and water, and through sterilization by means of heat.

Pathogenic Bacteria. Of the thousands of species of bacteria in existence, only a small number are able to produce disease in man. These are scattered through the three groups discussed on page 207. The majority belong to the rod-shaped forms, a smaller number are spherical, and a few are spiral.

Many disease bacteria are definitely *parasitic* in their habits of growth; at least they do not seem to multiply to any great extent in natural organic materials outside the living body. Upon leaving the body of the patient, many of them die in a short time, probably because of the drying influence of the air and other unfavorable conditions. Due to these characteristics of the pathogenic bacteria, the control of contagious diseases is less difficult than it would otherwise be.

Many pathogenic bacteria, however, are, in a certain sense, *saprophytic*; for they grow readily in or upon such artificial substances as broth and other types of culture media. Some organisms, notably those that cause tetanus, or lockjaw, are said to be habitually saprophytic. These grow best in certain types of decomposing organic matter, but they can, when introduced into wounds, produce very serious effects. However, it is doubtful to what extent even these germs may multiply in the soil and other materials outside the bodies of animals. (Page 182.)

Spore Production in Pathogenic Bacteria. Among the few disease bacteria that produce spores are the tetanus and anthrax

organisms, both of which cause dangerous diseases. These spores, like those produced by ordinary bacteria, are extremely resistant to heat and drying, and are able to live for a long time under unfavorable conditions. The fact that spores are not produced by the bacteria of our common diseases, such as diphtheria, typhoid, and tuberculosis, is obviously of far-reaching importance in the successful application of protective measures against disease.

Pathogenic Protozoans. There are a number of human diseases caused by minute one-celled animals, generally referred to as the *protozoans*. Notable among these are the various forms of *malaria*, one type of *dysentery*, and several dangerous tropical diseases, the most important of which is *sleeping sickness*, prevalent in the Congo region. A serious disease of cattle known as *Texas fever* is also caused by a germ of this type.

Contagious and Infectious Diseases. Definitions. A *contagious* disease is one that is transmitted from the diseased person to another individual through *contact*. An *infectious* disease is one caused by living organisms, such as bacteria or other germs. It will be seen that the former term emphasizes the *method of transmission*, while the latter refers more definitely to the *cause of the disease*. Some infectious diseases are not generally looked upon as contagious, as for example, typhoid fever and malaria. On the other hand many germ diseases are definitely contagious.

Steps in the Transmission of Infectious Diseases. Since infectious diseases are caused by living organisms that develop within the body of the individual, it is necessary, before transmission can take place: 1. That the germs *escape* from the body of the patient; 2. That these be *carried* to the second individual; and 3. That the germs *gain entrance* into the body of this individual. Modern measures employed against infectious diseases are based upon these general principles.

Examples. The ordinary precautions in regard to coughing and sneezing in the presence of others during epidemics of throat infections, and the disinfection of the intestinal wastes from the typhoid patient are for the purpose of preventing the escape of germs from the body. The cleaning up of towns and cities to prevent the

breeding of flies and mosquitoes interferes with the carrying of the germs of typhoid, malaria, and numerous other diseases. Finally, cleanliness in regard to foods, and antiseptic dressings for open sores prevent disease germs from gaining entrance into the body.

Direct Contact as a Means of Transmission of Disease. The importance of the direct transmission of germs from the diseased to the well can scarcely be overemphasized. For many years it has been known that certain diseases, such as smallpox, measles, and scarlet fever, are disseminated in this way. Of recent years this method of transmission has been shown to be very common, and now it is looked upon as the chief means of communicating a large number of infectious diseases. The surest way to escape most contagious diseases is *to avoid personal contact with the individuals suffering from them.*

The intermingling of people in closed rooms or in crowded cars offers the best opportunity for this type of transmission. Coughing and sneezing by individuals having infectious diseases, or by those who are harboring the germs in their throats—a condition now recognized as quite common—is very dangerous. The droplets of mucus, laden with active bacteria direct from the patient, may remain suspended in the air of a room for some time, and may readily gain entrance into the throat or nasal passages of anyone near. Coughing and sneezing in the open air are much less dangerous because of the rapid scattering of the droplets by currents of air, which renders infection much less probable.

Open Air and Disease Transmission. A generation ago, air was looked upon as an important means for the dissemination of disease germs, but of recent years this view has been modified. Most active disease germs are unable to survive any great length of time when exposed to the drying influence of ordinary air, and the effect of direct sunlight is deadly to them. These facts seem to indicate that bacteria-laden dust particles probably are not of great importance in the spreading of diseases. It is possible that germs capable of withstanding adverse conditions such as are encountered in the open air may be transmitted in this way; but this is looked upon to-day as of rather rare occurrence.

Water and Disease Transmission. Although disease bacteria, in general, do not multiply — to any great extent, at least — in water, yet this substance offers an important means for the dissemination of certain germs, notably those of typhoid fever and cholera, that ordinarily leave the patient by way of the intestinal discharges. Pathogenic organisms survive much longer in water than they do in the open air.

How long germs may live in water depends to a considerable extent upon the amount of organic matter present. In pure water, however, it seems that they may live for a few days. The drinking of infected water is the most important but not the only means by which epidemics of typhoid fever and cholera are started. The care taken to obtain water from a safe source, and the large amounts of money spent in purifying it indicate the importance which health authorities attach to this means of disseminating disease.

Foods as Related to the Transmission of Disease. It was pointed out in the preceding chapter that the cooking of foods was a great safeguard against the transmission of disease germs. The danger of infection lies in the use of food that is uncooked or that has become contaminated later.

The germs that may be transmitted in this way are those of typhoid and of other diseases that infect through the digestive tract. The food that is most likely to become contaminated with pathogenic organisms is *milk*. Epidemics of typhoid and many intestinal complaints of children have been traced to this source. *Raw vegetables* that have been grown in soil polluted with fresh sewage, as is sometimes the case near cities, are dangerous if not cleaned with great care; for they may carry typhoid germs. Likewise *oysters* that have been in water contaminated with these germs are known to be dangerous if eaten raw.

Food Poisoning. Certain diseases which are transmitted solely through the food are included under the term *food poisoning*. Such troubles are extremely common, often appearing as a simple digestive disturbance, but not infrequently as a very serious disease. The various species of bacteria responsible for this trouble are some-

times present in protein foods, generally meats, and if taken into the digestive tract, may bring about sudden illness.

Insects and the Transmission of Disease. A number of species of our common insects are now looked upon as a serious menace to health, and in many communities much care is taken to prevent their breeding. Most important in this country are the *house flies* and certain species of *mosquitoes*; but in other countries, *fleas* and *body lice* also are agents in disease transmission. Some ailments of domestic animals are carried by forms closely related to insects; for example, Texas fever is carried by the *cattle tick*. Of recent years the general subject of the transmission of disease by insects has come to be considered highly important in connection with the control of some of our most serious epidemics; and the destruction of the insects concerned is frequently very successful in checking such outbreaks.

Human Carriers. Recently it has been shown that individuals who are apparently in good health may harbor germs of various diseases and be able to transmit them to others. Such individuals are spoken of as *human carriers*. The best known cases of this nature are the typhoid and diphtheria carriers; but there is little doubt that a number of other diseases are disseminated to a considerable extent by the same method.

Routes by which Germs Enter the Body. There are several routes by which disease germs may gain entrance to the tissues of the human body: 1. The mouth and digestive tract, 2. The respiratory tract, 3. Through the skin, and 4. Through mucous membranes. These will be discussed later.

Distribution of Disease Germs in the Body. Pathogenic organisms differ considerably in their distribution in the body. Some remain near the place of entrance, while others are often widely scattered through various tissues. The germs of diphtheria are generally confined to the membranes of the throat or nasal passages, and those of tetanus and certain others that enter through wounds are also localized. The bacteria of typhoid, pneumonia, and some other germs are often carried in the blood and are broadly distributed through the organs of the body. Some kinds of bacteria,

such as the ordinary pus-forming species, although ordinarily localized, may under certain conditions gain entrance to the blood and even multiply there. When this occurs they give rise to what is commonly known as blood poisoning.

The Effect of Bacteria upon the Body. Just how the presence or development of pathogenic bacteria within the human body brings about the condition we call disease, is not in all cases entirely clear. With some forms, such as the germs of diphtheria and tetanus, the harmful effects are due to poisonous substances, called *toxins*, produced by the bacterial cells. These toxins come into contact with various organs, through the blood or otherwise, and interfere with their functioning.

Distribution of Toxins in the Body. With many diseases the facts are not so clear. In some cases toxins seem not to be produced outside the body, although it is possible that they may be secreted when the germs are developing in the living tissues. In others, it appears that the substance of the bacterial cells is poisonous and brings about the symptoms of the disease when the bacteria break up. It may be that in certain cases the mere presence of tremendous numbers of germs in some way interferes with the functioning of an organ, thus producing the effects characteristic of the disease.

In the case of diphtheria, the toxin secreted by the germs, which are generally localized in the throat or vicinity, is carried by the blood. The most important effect of this poison is its harmful influence upon the heart and kidneys. With tetanus, the toxin seems to pass through the nerves until it finally reaches certain portions of the central nervous system. The toxin in these cases may be obtained through the growth of the germs in culture media outside of the body. If this product, freed from all bacteria, is injected into a susceptible animal, the symptoms of the particular disease result just as if the germs were present.

Physical Condition of the Body and Disease. A factor of the highest importance in regard to the contraction of disease is the physical condition of the human body itself. The *well-nourished, healthy body* is by far the *greatest safeguard against the en-*

trance and development of most disease germs. Any condition that tends to reduce the natural resistance — and there are many of them, such as poor food, lack of sleep, and exhaustion — predisposes one to infectious diseases.

Obviously, if one could escape being exposed, it would be an easy matter to prevent infectious diseases; but this is impossible with many of the common complaints, such as the various types of throat troubles and other ailments where the germs are likely to be widely disseminated. It is true that considerable care is generally taken to prevent the dissemination of the bacteria of our more serious diseases, such as diphtheria, typhoid, and tuberculosis; but even here there is the likelihood of accidental exposure at almost any time.

Resistance of the Human Body to Disease. The healthy human body is remarkably well adapted to combat the various types of disease germs, either by preventing their entrance and growth, or by finally overcoming them through substances formed after the symptoms of the disease appear. The fact that so many diseases are cured is an indication of the effectiveness of this protection. The remarkable mechanism for the combating of the germs in the human body involves several distinct factors, among which may be mentioned *white blood corpuscles*, *antitoxins*, and *bactericidal substances*. If the body lacks these substances, it is open to attack, and the failure to combat the germs at the beginning generally results in the contraction of the disease.

White Blood Corpuscles. The blood of higher animals, including man, is composed of two kinds of corpuscles, the red and the white, suspended in the liquid portion, or plasma. The white corpuscles differ from the others not only in color and structure, but also in function. The red are concerned with the carrying of oxygen, but the white have no direct connection with this process.

The white corpuscles behave in the body somewhat as independent one-celled animals. They are distributed not only throughout the blood, but also through the tissues, where they doubtless perform valuable service by aiding in the removal of foreign substances or superfluous tissue. The sinews used in stitches in wounds are absorbed in this way.

Phagocytes. Of the several types of white blood corpuscles in the body, one, known as the *phagocyte*, is of great interest to us in considering resistance to disease, for these phagocytes play a very important part in the protection of the human body from invading organisms. These "wandering cells," as they are sometimes called, are able to ingest disease germs, very much as the lower protozoans take in their food from the water in which they live. In this way phagocytes doubtless destroy large numbers of bacteria that gain entrance into the tissues.

Pus Formation. When the bacteria are numerous and are not speedily overcome, many of the white corpuscles are destroyed, probably through the effects of the germs. These dead cells make up a considerable portion of the *pus* which is produced under such conditions.

Antitoxins. Antitoxins are chemical substances secreted by the living cells of the animal body. The presence of toxin from bacteria, or from other sources, in some way stimulates the tissues to increase the amount of antitoxin normally in the body. The most striking characteristic of these substances is their power to unite with toxins and thus render them inert. Antitoxins are specific in their action; that is, a particular kind is needed to react with a given toxin. For example, diphtheria antitoxin, although it is very effective in neutralizing the toxin produced in this disease, has no effect upon a different type, such as that derived from tetanus germs.

Bactericidal Substances. Another factor of great importance in the resistance of the body to disease is the power of the blood to destroy disease germs. This result is accomplished through the presence of certain products in the blood, referred to as *bactericidal substances*, which are secreted by the cells of the body and are often present in the serum of immune animals in sufficient amount to destroy large numbers of bacteria. During the course of a disease, bactericidal substances deadly to the germs concerned are produced and aid much in overcoming the attack.

The Method by Which Diseases Are Cured. During the progress of a disease, the possibility of cure rests largely upon the remarkable activities by which the body protects itself. Certain

treatments and medicines may aid in the acquiring of this resistance, but the old ideas concerning the specific curative powers of drugs have given place to the view that the *body cures itself*.

This conception is not antagonistic to well-established remedies, many of which are of great value in the treatment of disease; but it does emphasize strongly the importance of the bodily condition rather than the direct influence of drugs in the overcoming of disease. The tendency at present, which is certainly based upon sound scientific principles, is to *rely less upon medicine* as a curative agent, and *more* upon those factors that have to do with the *improvement of one's physical condition*. The modern system of scientific nursing is a direct outgrowth of these fundamental principles.

Prevention of Disease through Hygienic Practices. The bodily condition is also of the highest importance in the prevention of disease. The systems of physical training in schools and in other institutions, and the emphasis now placed upon bodily hygiene are doing much to impress this fundamental truth upon people in general. In short, the well-nourished body, supplied with plenty of fresh air, and kept in good physical condition by sufficient and suitable exercise, is without doubt the most effective means for the prevention of disease.

SOME IMPORTANT HUMAN DISEASES ¹

TUBERCULOSIS

The Serious Nature of the Disease. Of all diseases of civilized countries, tuberculosis is looked upon as the most serious. It has been referred to as the "great white plague" and truly, when one considers its prevalence and the results attributed to it, the term seems entirely fitting. Generally it does not cause the same fear and dread that often resulted in former times from spectacular epidemics of smallpox or in recent years from the dreadful visitation of the "flu"; nevertheless, it still holds its place at the head

¹ Many government bulletins as well as some publications from state Boards of Health provide excellent materials upon this subject. See Bibliography.

of the list of dangerous diseases. Instead of carrying off large numbers in a community in a short time, it works slowly, and gradually the patients waste away and die. The large total number of deaths is accounted for by the fact that the disease is prevalent over a wide area.

Its Occurrence. Tuberculosis is probably the most prevalent disease to-day among civilized races. High authorities estimate that more than ninety per cent of all mature people have it during some period in their lives. Others place the estimate somewhat lower, but there seems to be no doubt that a majority of people contract the disease at some time. These facts are based upon the examination of many individuals who have died of other causes, and yet show unmistakable evidences of the earlier presence of the germs of tuberculosis in various parts of the body. If these estimates are true, and we have no reason to doubt them, then it must follow that a large percentage of cases of tuberculosis is cured, for only a comparatively small proportion (about ten per cent) of the total deaths results from this disease.

Tuberculosis a Curable Disease. A generation or two ago, tuberculosis was looked upon as one of the most fatal of all human maladies. In fact, it was often referred to as incurable; and about all that could be done, according to the views then held, was to make the patient as comfortable as possible and await the inevitable end.

This hopeless way of looking at the matter in the past was due to the fact that the disease was not recognized until it had reached the final stages, and until hemorrhages resulting from the breaking down of large areas of lung tissues had occurred. At this period, even to-day the disease is considered to be very dangerous, although remarkable cures do sometimes result. The modern physician generally identifies the germ or suspects its presence long before the body is so weakened that resistance is impossible. Consequently, through treatments applied in the early stages, the disease is often checked.

Recovery from Tuberculosis. In a large majority of cases, tuberculosis is overcome through the *resistance of the healthy body*

itself *before the germs develop sufficiently to produce any definite symptoms*. Doubtless, the germs begin to develop at times when the body is run down through the effects of wasting diseases or other causes; but when the physical condition of the body improves sufficiently, the disease is checked.

The Germs of Tuberculosis. The germ that causes this disease is a short, rod-shaped organism. No spores are produced, but the bacteria are somewhat more resistant than many of the other common disease germs. There is evidence that they may live for a week in dust formed from the sputum of a tubercular patient, and in masses of dried materials for a much longer time. They are also quite resistant to dry heat, but when in water a temperature of 60° C. (140° F.) maintained for twenty minutes is fatal to them.

The germs are also resistant to various disinfectants. A five per cent solution of carbolic acid added to sputum requires twenty-four hours for complete disinfection. This is due in part to slow penetration of the chemical. The saliva seems to protect the germs to a considerable degree. It is therefore evident that the germs of this disease are not as readily killed as was once supposed.

Although the disease is probably scattered most commonly through personal contact, as was pointed out on page 238, yet evidence indicates that there may be danger at times from dust or food contaminated with living bacteria that have resisted drying and other adverse conditions.

The Germs in the Body. There are a number of types of tuberculosis differing chiefly in the location of the bacteria in the body, and consequently in the effects produced upon the individual. In the most common, as well as the most dangerous, form of the disease, the germs develop in the *lungs* and destroy the tissues. Other types are tuberculosis of the *intestines*, the *bones*, the *joints*, the *lymph glands* of the neck, and the *skin*. In fact, almost any organ or part of the body may be invaded by these bacteria.

Formation of Tubercles. A general result of the growth of the bacteria causing tuberculosis is the formation of small nodules or tubercles which are visible to the naked eye, and from which the disease takes its name. In the beginning these structures are made

up of cells of a special type, which later degenerate and die. Later certain mineral substances are often deposited in the tubercles, and the whole mass may be completely separated from the surrounding tissues. These formations remain permanently in the organs of the body and constitute the evidence of earlier infections.

The Escape of the Germs from the Body. The tubercle bacteria generally leave the body of the patient in the sputum or in droplets of mucus expelled from the mouth or nose. A person suffering from tuberculosis of the lungs may expectorate billions of tubercle bacilli in twenty-four hours. Many of these die soon after coming into contact with sunlight and the drying action of the air; but there is evidence that some may live for a long time, even months, in dark enclosed spaces. Under such conditions, considerable danger may exist in rooms recently occupied by tuberculous patients.

Infection by Droplets of Mucus and Dust. Droplets of mucus and infected dust are a serious menace to those closely associated with a patient who coughs. In infections of the skin and other portions of the body the germs are not likely to be scattered if reasonable precautions are taken.

Entrance of the Germs into the Body. The germs of tuberculosis from dust in the air sometimes enter the *lungs* and develop there. In former years this was looked upon as the most probable mode of entrance of these bacteria. Recently, however, this view has been losing ground and now emphasis is being placed upon *intestinal* infection. The germs may be carried into the mouth by the hands, the food, droplets of mucus, or dust, and thus gain access to the digestive organs.

It has been demonstrated beyond doubt that the germs may enter the system through the walls of the intestines and be scattered to different organs of the body. Some authorities hold that a large proportion of lung infections arise in this manner. Although the percentage of these cases may not be large, the consensus of opinion is that they do occur at times.

Diseased tonsils and the growths in the nasopharynx known as *adenoids* may offer a ready means of entrance for the germs of

tuberculosis, and may also be predisposing factors to the disease by interfering with the breathing and the general health.

Conditions That Favor Tuberculosis. The crowded tenements, where whole families are undernourished and live in a single, poorly ventilated room, provide conditions most conducive to the development of this disease. On the other hand, among the well-to-do classes and among those who spend considerable time in the open air and eat plain but wholesome food, the disease is much less prevalent, and also less often fatal. Probably there is no disease that is more definitely influenced by living conditions than tuberculosis.

1. The *influence of occupation* upon the death rate from this disease is shown by statistics collected in London. These indicate that the fatalities among those who work upon farms are only about a fourth as great as among the workers in the manufacture of earthenware, cutlery, glassware, and in other trades of similar nature, where much dust is encountered. The dust which reaches the lungs and air passages seems to cause irritation and prepare the way for the development of the disease. Other important factors in increasing the death rate of industrial workers are the poorly ventilated rooms and unsanitary conditions of the buildings where these people are so often employed.

2. Excessive *heat and dampness* also predispose to tuberculosis. Laundry workers and others who are employed in moist and warm rooms show a high death rate. But neglected ventilation in these establishments and the general living conditions of the workers are also influential.

3. Probably one of the most important factors preparing the way for active tuberculosis is the effect of *wasting diseases* upon the general resistance of the body. It was pointed out in the preceding chapter that colds and whooping cough lower the vitality of the body in general, and doubtless interfere with the production of the protective substances in the blood. It is probable that of all dangerous diseases, tuberculosis is the most common outcome of such a non-resistant condition of the body. In fact, some writers hold that the germs of tuberculosis are often present in the body in an inactive

state until some conditions arise which make it possible for the organisms to develop and produce the active forms of the disease.

4. Another factor that predisposes to this disease is a *poorly nourished condition of the body*, which may be brought about by food insufficient in quantity or of a type unsuited to the individual.

Even members of well-to-do families may be found to suffer from malnutrition. The physical condition of many public school children has been greatly improved and their resistance to disease has been increased by the hot lunch or glass of milk each day, and by the addition of green vegetables to their diet.

There are other predisposing factors to tuberculosis, such as *sedentary employments, undue exposure, and alcoholism*; but these need not be discussed here. It is sufficient to say that any condition that tends to weaken or lower the resistance of the body may prepare the way for this disease.

Heredity and Tuberculosis. In past years it was generally held that tuberculosis was inheritable and that children of tuberculous parents were likely to be born with the disease. Observations of the occurrence of tuberculosis in many families seemed to substantiate this belief. In almost every community even now, one or more examples may be found where several or all members of families are infected. Naturally this condition was attributed to heredity. The writer has in mind a case where both parents died of the disease, and all of their children as well as a large number of the grandchildren suffered from it.

When the evidence was studied critically, however, it became apparent that tuberculosis is not inheritable. There is no question but that it often occurs in several members of one family; but this can be explained in a much more satisfactory manner than by assuming that the disease is truly inheritable, or even that the bacteria are transmitted from parent to offspring through the germ cells. (Chap. XI.)

Direct infection of the offspring from diseased parents is doubtless the main cause of the appearance of tuberculosis in families and of its apparent hereditary character. The close association of parent and child during the early years of childhood offers abundant

opportunity for direct transference of the germs. Moreover, the high susceptibility during the early years of a child's life and the kissing of children by the parents throw additional light upon the matter of transmission of tuberculosis from parent to offspring.

It is probable that heredity is involved, to some extent, in the appearance of the disease in families. There seems to be no question that certain characteristics resulting in a low degree of resistance may be inherited in just the same way as various family traits are passed on from one generation to the next. Such "tendencies" may predispose to the disease; but it should always be kept in mind that an attack is the *direct result of infection*.

Tuberculosis in Lower Animals. Many mammals are susceptible to tuberculosis, and the disease is also common among fowls. The form occurring in poultry seems to be quite distinct from the human type. Cattle, hogs, and many animals in zoölogical gardens are frequently infected with a form of the disease apparently very similar to human tuberculosis. Of these, the domestic animals just mentioned are of great interest to us.

The disease among cattle and hogs is very prevalent at times, sometimes affecting large numbers of them. A high percentage of the cattle of dairy herds is frequently found to be infected. In one case that came under the writer's observation, inspection showed practically the entire herd to be tubercular. The disease among cattle on the range is not nearly so prevalent, and the same is true of hogs kept in open fields, although a considerable percentage of these are sometimes found to be infected. Probably the seriousness of the disease among dairy cattle is due largely to the special conditions under which they are kept.

Type of Tuberculosis in Cattle. Whether tuberculosis of cattle is identical with that of human beings is a question that cannot be answered definitely at present. The two diseases appear to be very similar, to be sure; but there is evidence that the germs differ considerably. There seems to be no doubt that infection in man may result from the germs of bovine tuberculosis, but how frequently this is the case is a question. In the past some high authorities have asserted that there is great danger from this source, and

others have said that there is little or no danger from milk and other dairy products.

To-day the view is becoming quite generally accepted that tuberculosis of cattle and hogs is a real menace, especially to young children, and that as a consequence every precaution should be taken to prevent possible infection. *There seems to be no doubt that the really safe procedure is to avoid the use of milk, butter, and other unsterilized products from tuberculous animals.*

Control of Tuberculosis. The prevention of tuberculosis is one of the most important problems concerned with public health. Whether the disease is chiefly contracted in the early years of childhood, as some authorities assert, or whether the germs may enter at any time and cause the active forms of the disease, the methods of prevention are the same and consist of two general precautions. 1. Avoid infection in every way possible. 2. Avoid all influences that tend to lower the general resistance of the body.

Difficulty of Avoiding Infection. Since tuberculosis is infectious, obviously there could be no attack of the disease if the germs were kept out of the body. From the evidence concerning the prevalence of the disease, the realization of this hope is apparently not very near at present. There is no doubt, however, that much good would result if those who have active forms of tuberculosis would try to prevent the dissemination of the germs through spitting, coughing, and in other ways. It is certainly a wise precaution for everyone to avoid the presence of patients who are coughing and to look carefully to the food supply, especially where there is any danger of contamination.

Resistance of Body. It cannot be emphasized too strongly that the *human body in vigorous health is, after all, man's greatest asset in the control of any disease.* If exposure can be avoided, it should be; but when this is not possible, as is too often the case, then the final line of defense lies in the resistance of the body itself. This depends very largely, as was pointed out in the previous chapter, upon the physical health of the individual.

Tuberculosis Treatment. Modern treatment for preventing tuberculosis as well as for checking advanced cases consists very

largely in improving the physical condition. *Good food, plenty of fresh air and sunlight, and proper exercise*, which may mean almost complete rest in some cases, have frequently been very effective in the cure of patients even in the advanced stages of the disease. The effectiveness of these same factors in the prevention of disease, whether tuberculosis or some other malady, is now universally recognized.

A Well-nourished, Resistant Body a Priceless Possession. In robust health the greatest care should be exercised to maintain this condition; and in disease every precaution should be taken to aid the body to regain its former vigor. Consequently the practices that are of the highest value in preventing tuberculosis or other diseases are identical with those which everyone, whether ill or not, should observe, if the body is to be kept in vigorous health. The fact that tuberculosis is so often cured is due to the resistance of the healthy body itself, which often overcomes the germs long before their presence is even suspected.

Precautions To Be Observed by Tuberculous Patients. Since the germs escape from those suffering from tuberculosis of the lungs through the mouth or nose, extreme care should be exercised in the disposal of the substances coughed up and of the mucus from the nostrils. The most effective as well as the safest method is to burn these substances. It is recommended that the sputum be deposited in paper napkins and boxes, which may be placed directly in the fire. Spitting upon the floor or soil is a serious menace to others.

TYPHOID FEVER

Importance of Typhoid Fever. Typhoid fever is one of the most dangerous bacterial diseases prevalent in civilized countries. Although it does not cause nearly so many deaths as are attributed to tuberculosis, yet in localities where it gets a foothold, it often produces epidemics of the most serious nature and, for the time at least, becomes more feared than tuberculosis.

Occurrence of Typhoid Fever. Typhoid fever is primarily a filth disease, and the germs are practically always transferred from

the patient to others directly or indirectly through the wastes from the human body. Consequently the disease is far more likely to appear in situations where sanitary conveniences are poor or altogether lacking. In rural regions where human sewage is often disposed of in careless ways, and in small towns where this material is accessible to house flies and where it may contaminate the water supplies, typhoid often appears and causes great loss of life.

Typhoid in Armies. In former years, before the adoption of the modern methods of prevention, typhoid was a most serious disease of armies in the field as well as in camp, sometimes causing more loss of life than the bullets of the enemy. This was the case in the Spanish-American War. Such extreme prevalence was due very largely to the absence of sanitary conveniences, together with the presence of flies, which made it almost impossible to avoid contamination of food and water used for human consumption. The prevention of this disease in army camps and like situations, notably during the Great War, is one of the great medical triumphs of modern times.

Prevalence of Typhoid. Statistics indicate that there are in the United States every year some 30,000 to 40,000 deaths due to typhoid. Since it appears that only about one in ten cases is fatal, there are annually something like 300,000 to 400,000 cases of typhoid fever in this country. When one considers that this is a filth disease, and is scattered as stated above, it certainly indicates that there is much room for improvement in the disposal of sewage in this country. Certainly the public schools, health departments, and other educational agencies should impress upon everyone the importance of great care with reference to human wastes. Only through concerted action on the part of all the inhabitants of the community outside the larger cities can adequate sanitary measures be put in practice that will check outbreaks of typhoid which, in a great degree, are preventable.

Nature of Typhoid Germs. The germ that causes typhoid fever is a short rod-shaped form, quite similar to several others frequently associated with it in intestinal wastes. The fact that it is not readily identified complicates the problem of determining its

presence in water supplies, milk, or other foods. Health authorities usually condemn water supplies as dangerous, not because they actually find typhoid bacteria present, but because there is human sewage in the water, and consequently danger from this as well as from certain other intestinal germs.

Multiplication of the Germs Outside the Body. Typhoid germs ordinarily do not reproduce outside the body. There seems to be little if any evidence that they develop under ordinary conditions in water, soil, or even in sewage, although they may remain alive in these substances for considerable periods in a virulent state. In milk, however, they seem to multiply, at least to some extent — a fact of great importance in relation to the supply of this food.

Length of Life of Typhoid Germs Outside the Body. Typhoid germs do not produce spores; consequently they are not very resistant to heat, sunlight, and other germicidal agents. The bacteria are able to survive long enough when in sewage or in water, however, to be a real source of danger. Evidence seems to indicate that the germs may live in natural bodies of water for four or five days, or even longer, and still be able to cause infection. It is possible that water may remain dangerous from this cause for a much longer time, but this is not likely to be the case, at least in flowing streams. Evidence points very definitely to the fact that *fresh sewage in water is most dangerous*.

On the other hand, it is said that the germs may live for months in the soil and in privy vaults. This fact indicates the danger that may arise from scattering human wastes upon the soil, either as a fertilizer, or as a means of disposal, for the germs may readily find their way through surface water to wells or streams and cause serious pollution. In some localities, generally near large cities, such materials are sometimes used to enrich the soil of vegetable gardens — a practice that is unsanitary and dangerous, especially in connection with products that are consumed in the raw state.

The Entrance of Typhoid Germs into the Body. Typhoid bacteria enter the system through some portion of the digestive tract. So far as is known at present, the germs cause infection in no other way. In former years it was generally held that this always

takes place through the walls of the intestines, but recently investigators have called attention to the probability of infection by way of the tonsils or other portions of the alimentary canal. Some authorities place great emphasis upon diseased throat tissues as a means of entrance for typhoid as well as other germs.

It follows that infection is the result of eating or drinking *polluted food or water*, or possibly of taking into the *mouth* materials containing *germs carried by flies* or other agents. In times when typhoid is prevalent it is a matter of the highest importance to use every precaution in preventing the germs of the disease from entering the digestive tract.

The Germs in the Body. It was formerly thought that the germs were located mainly in the walls of the intestines, where they cause ulcers; but it is now known that they become widely scattered throughout the body. They occur in the blood of most patients early in the course of the disease—a fact now made use of in diagnosis. After death the germs are present in practically every organ of the body.

Intestines. Typhoid germs are not excessively abundant in the intestinal contents as a general rule, and sometimes they appear to be practically absent from the stools of a patient. This may indicate that the bacteria do not multiply, at least extensively, in the intestinal contents, but simply find their way there from some organ where they are actively developing. Evidence at present points very definitely to the gall bladder as an important source of the germs that occur in the intestines.

Gall bladder. Post-mortem examinations of human bodies, as well as laboratory experiments, have shown not only that the bile becomes infected in the course of the disease, but also that the germs may continue to exist in the gall bladder for months after they have disappeared from other organs. These facts throw much light upon the so-called “typhoid carriers.” (Page 259.)

Bladder. In a considerable proportion of cases, the urine becomes infected with enormous numbers of the germs, a condition that may continue during the convalescence of the patient, and even for months after health is regained. Obviously this may become

a serious menace if special care is not exercised in the disposal of such wastes.

Effect of Germs upon Intestines. During the progress of the disease, the germs attacking certain portions of the intestinal walls bring about the formation of swellings or ulcers which may so weaken these tissues as to cause danger of rupture. This is to be guarded against with the greatest of care. Food that might form hard masses in the intestines and thus cause a break in the walls, and all straining movements of the body that might produce pressure upon the abdominal organs should be carefully avoided.

The Escape of the Germs from the Body. Typhoid germs leave the body practically always in the intestinal wastes or in the urine. They have been found in the sputum at times, but this is probably of little or no consequence. The fact that the bacteria leave the patient as they do and enter the second individual by way of the mouth is, to say the least, rather startling. Every case of typhoid fever that occurs indicates a more or less direct *transfer of human wastes to food, or to the mouth of the infected individual.*

Disposal of Sewage. The disposal of human wastes in the average community is not an easy problem. In cities of considerable size, well-informed boards of health take charge of the situation and relieve the individual citizens of responsibilities other than that of obeying the rules. Ordinances are passed that in well-regulated districts are rigidly enforced, with the result that sanitary conditions are often quite satisfactory in places where the better classes reside. In the poorer parts, however, and in the outlying communities where careful supervision is more difficult, conditions are frequently far from ideal.

Sanitation in Small Towns and in the Country. The most serious conditions relative to typhoid and other intestinal diseases are found in small towns and villages where sewage systems are inadequate or altogether lacking, and where the water supply is not from a central source where it can be readily purified. Here the open privy, the dug well not far away, and the stable with its abundant manure for the breeding of house flies, constitute conditions

favorable to the outbreak of epidemics of typhoid and similar diseases.

In rural regions where families are widely separated there is little danger of extensive epidemics of typhoid. The sanitary conditions about the individual homes, however, are often very poor, and consequently, scattered cases of the fever occur frequently.

Epidemics of Typhoid Fever. Outbreaks of this disease are of such common occurrence in this country, and often of so serious a nature, that much attention has been given to them by health authorities. No disease has been more carefully studied, and both the causative organisms and the means by which they are disseminated are well understood. Yet, large numbers of cases continue to appear and result in thousands of deaths every year. This is mainly due to a lack of information or to carelessness regarding sanitary matters on the part of the general public. A brief survey of the more important ways by which the germs make their way to new victims will serve to throw much light upon typhoid epidemics and upon infections in scattered cases.

Cause of Epidemics. There is no doubt that a polluted water supply is the most common cause of typhoid epidemics. Likewise many isolated cases in rural regions and in small towns may be traced to wells or streams contaminated by sewage. The river or smaller stream receives the sewage of one town and furnishes the water for another a few miles away; or the sewage of the family in the country or in the small town is deposited in a cesspool or on the soil, where the bacteria may be carried in the surface water to the dug well.

Sanitary Water Supplies and Typhoid. Were it not for the careful purification of the public water supplies of many American cities, the conditions would be very much worse than they are. This general supervision by experts obviously cannot be employed in the rural districts and in the small towns. Consequently, the inhabitants of these localities are thrown largely upon their own responsibility in the matter.

In this situation the greatest care should be taken to avoid water from questionable sources. If there is any doubt as to its purity,

boil the water which is to be used for drinking purposes. It is a wise precaution when on a picnic, or in a strange locality, to refrain from drinking water from an unknown source unless it has been boiled.

Milk and Typhoid. Epidemics of typhoid due to polluted milk are of rather common occurrence. The bacteria may gain access to the milk through polluted water used in washing the cans, through the handling of the product by uncleanly persons who are carriers of the germs, and through the agency of flies. Pasteurization of milk kills typhoid bacteria as well as many other types of disease germs and, consequently, is a great aid in avoiding infection.

Other Foods and Typhoid. Some cases of typhoid, and even rather serious epidemics, have doubtless been caused by contamination of other foods, such as fresh vegetables and oysters. The bacteria upon the vegetables come directly or indirectly from human wastes. The bacteria in oysters come from infected sewage that reaches the beds from nearby sewer outlets.

Direct Contact and Typhoid. Another method of practical importance by which typhoid germs are disseminated is exposure in the sick room. The disease is generally looked upon as not very contagious; but it should be understood that there is considerable danger in the immediate vicinity of the patient, unless great care is used. Although the germs, as a rule, do not leave the body through coughing and sneezing, yet the bacteria may be transferred to those caring for the patient, through the handling of soiled clothing and the removal of intestinal and liquid wastes. A person serving as nurse should use extreme care to prevent the possible contamination of his own food, and to keep the germs from reaching his own mouth from dirty hands or in other ways.

Flies and Typhoid. The relation of house flies to the occurrence and spreading of typhoid fever as well as other diseases is worthy of the most careful consideration. In well-regulated cities where sewage systems are adequate, the danger from this source is much less, but in the average American small town and rural district where open privies are scattered along the alleys, or are in close proximity to the dwelling, the case is very different. Flies

have access to human filth and are a serious menace to health during the warmer months.

“Typhoid-carrier.” This term is generally applied to a human being who has recovered from an attack of typhoid but still harbors the germs in his body. In Germany investigations show that about four per cent of all who suffer from this disease become “chronic typhoid carriers.” In our own country there is abundant evidence that a considerable portion of those who recover from the fever continue to spread the bacteria, in some cases for many years. In New York a cook of uncleanly habits was responsible for the appearance of over two dozen cases of typhoid in several families where she was employed. Many other examples of a similar nature are on record. It seems to be very difficult to rid carriers of germs. The most practical means of control is to place such individuals at types of work where it is not possible for them to contaminate food or scatter the bacteria in other ways.

Significance of Carriers. The chronic carrier of typhoid germs is one of the main factors concerned with the spreading of typhoid fever. The fact that a person apparently in perfect health may be scattering these bacteria makes the carriers much more dangerous from the standpoint of sanitation than are the patients ill in the sick rooms. In the cases of the carriers, the danger is frequently not suspected, while with the others, precautionary measures are generally taken to prevent the escape of germs. It is not too much to say that the problem of the human carrier is one of the most significant, confronting health authorities everywhere not only from the standpoint of the danger involved, but also from that of the difficulties encountered in the control of the situation.

Vaccination for Typhoid. Of recent years, and notably during the Great War, vaccination has proved to be extremely effective as a preventive measure against typhoid. This treatment is now quite generally used in army camps, or other situations where large numbers of individuals are thrown together under poor sanitary conditions. The effectiveness of the measure indicates that it should come into general use in times of typhoid epidemics.

Method of Vaccination. Vaccination for typhoid is a very

simple operation, and as applied at present is practically devoid of danger to the individual. Permanent injury from its use is extremely rare, as is shown by the millions of treatments during the late war. The method generally used consists essentially in the injection of dead typhoid germs into the body in three successive doses given at intervals of a few days. The presence of these bacteria results in the formation of protective substances in the blood that are able to overcome the virulent organisms that gain entrance through the digestive tract, as was pointed out in the preceding section. (Page 243.)

Typhoid in Domestic Animals. In direct contrast to tuberculosis, typhoid fever seems never to occur in domestic animals. There is evidence that the germs are rapidly destroyed in the intestines of cattle. Consequently there seems to be little if any danger of the dissemination of typhoid bacteria by these animals, drinking polluted water.

Precautions To Be Observed in the Sick Room. Although typhoid in general is not considered very contagious, it is always wise to isolate the patient so that persons, not necessary as nurses, may not come in contact with the clothing and possibly infected materials of the sick room. All dishes and linens used about the patient should be handled with care and frequently disinfected by boiling water. The nurse, while washing and dressing the patient, or in changing the bed, is very likely to come into contact with the germs. Careful washing of the hands and face after such service should not be neglected. The use of some disinfectant, especially upon the hands, is also advisable.

Disposal of Wastes of Patient. The greatest danger from the sick room, however — at least so far as other individuals than the nurse are concerned — is in connection with the disposal of the intestinal wastes and the urine of the patient. They should never be disposed of without first being thoroughly disinfected. This may be accomplished through the use of a strong carbolic acid solution, milk of lime, or some one of the other chemical germicides.

DIPHTHERIA

Dangerous Character of Diphtheria. Diphtheria is one of the serious germ diseases and is of frequent occurrence in this country as well as in Europe. Formerly it was looked upon with especial dread, because of its sudden appearance and of its very rapid progress, which often terminated in death. It was most fatal among children, and a generation ago, it was not uncommon for several from the same family to die of it within a few weeks. The disease is more marked in its contagious character than either tuberculosis or typhoid; and before the modern treatments were perfected, epidemics were of common occurrence and very deadly.

Importance of Prompt Care. To-day — thanks to one of the most remarkable achievements of science, the antitoxin treatment, — the disease, when taken in time and handled by approved methods, is looked upon as of rather minor importance. In fact some of the so-called minor diseases, such as whooping cough, are often more serious in their consequences than is diphtheria when it is treated by a well-informed physician. It should be clearly understood, however, that the disease is still dangerous, and that it is easily controlled *only when early recognized and promptly treated*. The bacteria cause the formation of characteristic patches or areas in the throat which are usually recognized without difficulty by an experienced physician.

Susceptibility to Diphtheria. The age of the individual has a remarkable influence upon his susceptibility to diphtheria. From well-founded evidence it appears that a large proportion of all cases occurs between the ages of one and ten. Adults and very young infants are not likely to take the disease.

The Diphtheria Bacillus. The germ that causes diphtheria is a short, non-motile, rod-shaped form that shows, under certain conditions, a marked tendency to take on various shapes. Unlike the typhoid bacillus, it is affected quite characteristically by certain stains, and consequently, may be speedily and easily identified. Fortunately, it is also readily grown in cultures. These charac-

teristics have proved of the highest value in the control of the disease, for they afford a means of early diagnosis, as well as a test for the presence of the bacteria in the throats of convalescents and others who may be carriers of the germs. Like most disease germs, these bacteria do not produce spores.

Resistance of the Germs. Diphtheria bacteria, like most other disease organisms, are easily killed in the actively growing stage by a moderate degree of heat. Water at a temperature of 60° C. (140° F.) or even lower, is sufficient to destroy them in forty-five minutes. On the other hand, the germs are quite resistant when in dried substances, such as portions of membrane from patients. In such material they appear to be able to live several months, and to be more able to withstand high temperatures. It is stated that under these conditions boiling water is fatal to them only after a considerable period of exposure. It is very probable, however, that a large majority of the germs die soon after leaving the body of the patient, through drying and the action of sunlight.

Transmission of Diphtheria Germs. Diphtheria germs enter the body almost exclusively through the mouth or nostrils, although they may sometimes enter by way of other exposed mucous membranes, such as the eye. The bacteria are generally localized in the tissues of the throat or nose, and consequently the saliva and excretions from the nostrils are practically certain to carry multitudes of the organisms. The sputum or droplets of mucus produced in coughing and sneezing are exceedingly dangerous as a means of spreading the disease. In fact, it is generally recognized that contact, more or less direct, with patients or others who may harbor the germs in their throats, is by far the most common way in which the disease is scattered.

Direct Contact Between People. Direct contact through the common drinking cup, the toys of children frequently placed in the mouth, and coughing and sneezing in closed rooms, are examples of ways in which the germs may be transferred. Among the numerous other means by which the germs may possibly reach the membranes of the throat or nose are dirty hands, food, and pet animals. Obviously, great care in the handling and disposal of materials from the

diphtheria patient is essential in the prevention of the spread of this disease.

Types of Diphtheria. The location of the bacteria in the body determines several rather distinct types of the disease, some of which are not thought of generally as closely related to diphtheria. In the most typical form, the infection is in the *pharynx*; the germs may be located lower down in the *larynx* and give rise to "membranous croup"; or in the *nasal passages*, where they cause membranous rhinitis or nasal diphtheria. There is some evidence that "*colds*" may sometimes be due to these bacteria. Besides producing these rather definite effects, there is no doubt that the bacteria may be harbored in the throat or other tissues of healthy persons without producing any apparent effect by their presence.

The Effect of Diphtheria Bacteria upon the Body. The presence of the bacteria in the tissues injures the surrounding cells and doubtless is concerned with the formation of the diphtheric membranes peculiar to this disease. The most characteristic effect of the germs, however, is due to the production of toxin that circulates through the system and affects various vital organs, notably the heart, the kidneys, and nerves. The harm done these organs is often of a most serious nature, and for this reason, a so-called mild case sometimes results fatally.

Diphtheria Toxin. The real nature of diphtheria toxin is not well understood, but some important facts concerning its origin and behavior are of importance. When diphtheria germs are grown in a culture in broth, toxin soon appears in the solution, and the liquid, freed of all bacteria, becomes very poisonous when injected into the blood of animals susceptible to diphtheria. The toxin when used in this manner speedily produces symptoms practically identical with those that appear when the diphtheria germs are present. From this evidence, it is clear that the effects of the disease upon the animal body must be attributed to the production of the toxin rather than to the mere presence of the bacteria themselves.

Formation of Antitoxin. Another very important characteristic of diphtheria toxin is its ability to stimulate the body to produce *antitoxin*, which, as pointed out in a preceding section, counteracts

the toxin itself and renders it harmless. Normally, antitoxin is formed during the progress of the disease, and, if the body is able to withstand the direct poisonous effects of the toxin produced through the growth of the bacteria, this antitoxin becomes a very important factor in overcoming the disease.

Diphtheria in Lower Animals. Unlike typhoid fever, diphtheria is found in a number of lower animals. Guinea pigs and rabbits are quite susceptible to it, a fact of importance in connection with the production of antitoxin used for treatments. On the other hand, horses and a number of the larger domestic animals are immune. Cats, dogs, and pigeons are also susceptible, and the relation of these animals to the household, especially to young children, makes the possibility of the dissemination of diphtheria germs by this means in times of the prevalence of the disease, a matter to be looked after with care. Fowl diphtheria, or *roup*, is probably not identical to the human type, although statements to this effect are sometimes made.

Importance of Human Carriers of Diphtheria. There is no doubt that the chief mode by which diphtheria is spread is through contact, more or less direct, between those who harbor the virulent germs and other individuals susceptible to the disease. Although the bacteria may live for some time outside the body, yet a large amount of evidence indicates that the chief danger is not from dust and the like, but rather from human carriers.

The Method by Which Germs Are Carried by Patients. Investigations show that about fifty per cent of convalescents cease to harbor the germs soon after the diphtheric membranes disappear from the throat. In other cases the bacteria persist for a few weeks or longer, while with a small percentage they are present for months after the individual is apparently entirely well. If the necessary precautions have not been taken, more than half of the members of the immediate family of a diphtheria patient may for a time harbor the germs in virulent conditions.

Carriers among School Children. Frequently, when the disease has broken out in a school, or in some other situation where a number of people are thrown into close contact, many of

those present have been shown to harbor the germs in their throats. Sometimes diphtheria bacilli are present in individuals who have not been closely associated with those suffering from the disease, but in these cases the bacteria are often non-virulent and consequently not dangerous.

Diseased Throats and Carriers. Diphtheria germs do not seem to remain long upon mucous membranes that are in a perfectly healthy condition, and it is probable that in most human carriers they are located in the diseased tissues of enlarged tonsils and adenoids, where they find lodgment in the irregularities on the surfaces; or perhaps they may find suitable locations for growth in the inner nasal passages. Wherever they are located, it is often a difficult matter to get rid of them.

Antitoxin and Its Use. Of recent years antitoxin has come into such general use as the preventive and curative treatment for diphtheria, that the scientific facts concerning its production and use are of interest to all. A clear understanding of the principles involved, and the precautions taken to avoid danger, should definitely remove any prejudice that may exist as a result of the early use of antitoxin before the modern methods were perfected.

Production of Commercial Antitoxin. Antitoxin for commercial purposes is produced in the bodies of relatively immune animals as a result of a series of injections of diphtheria toxin into the tissues just beneath the skin. Young horses are admirably adapted for this purpose on account of their size, their comparative freedom from diseases dangerous to human beings, and their ability to resist the poisonous effects of diphtheria toxin.

In actual practice, healthy young animals are selected with great care, and are subjected to close observation for weeks by experienced veterinarians in order to make sure that no diseases, such as glanders and tetanus, are present. After it is determined that there is no danger from this source, the horse is kept under excellent sanitary conditions and is given gradually increasing doses of diphtheria toxin, at intervals of a few days, extending over a period of two months or more. At first the amounts injected are comparatively small, but as the resistance of the animal increases, larger and

larger doses are employed until finally the amount used at a single treatment is many hundred times the initial dose.

The toxin is obtained from a culture of virulent diphtheria bacteria, and is carefully freed from all organisms before being used. As the treatment progresses, the amount of antitoxin present in the horse's blood increases until a high concentration is reached. If the horse has remained healthy throughout this period, a gallon or more of blood is drawn under aseptic conditions and allowed to clot. The yellowish serum which contains the antitoxin is carefully filtered and certain preservatives are added to aid in keeping the material. Finally the product is concentrated and thus freed from some undesirable substances, after which it is tested for strength and purity. During the entire process, the utmost care is exercised to prevent any possible contamination from dangerous bacteria.

The Reasons for Testing Antitoxin. The testing of the serum is a most important phase of the process of manufacture.

1. It is absolutely necessary to know that dangerous germs, such as those of tetanus and others, are not present, for the injection of a substance into the blood is a procedure that should be considered with the greatest care, especially when the body has been weakened by disease.
2. It is also necessary to know definitely the strength of the final product, in order to be able to estimate the proper amounts to be used under different circumstances.

Use of Guinea-pigs in Testing Antitoxin. The tests to obtain the information indicated above are made through the use of living guinea-pigs. These animals are very susceptible to many human diseases, and this is especially the case when the germs are placed in the body fluids. In practice, small amounts of the serum under question are injected into the bodies of healthy guinea-pigs and the animals are then kept under observation for symptoms of disease. If dangerous germs are present, the animals soon show evidence of the fact. By repeated inoculations the purity of the serum may be established.

Strength of Antitoxin. The unit of antitoxin is the measure of the strength of a given quantity of serum. This term is difficult to define in a way easily understood by elementary students. Omit-

ting all technicality, we may think of a *unit of antitoxin* as the amount of antitoxin that will counteract a fatal dose of toxin for a guinea-pig weighing 250 grams. The method of determining the strength of a given serum is far too complicated for discussion here.

Besides the tests indicated above, each lot of serum is rigidly examined from the bacteriological standpoint by means of cultures both for aerobic and anaerobic organisms.

When all of these tests have been made in the most painstaking manner and the results are satisfactory in every way, the serum is put up in suitable sterile tubes for distribution. These containers are so arranged that if reasonable care is exercised, the antitoxin may be administered to individuals with but slight danger of contamination.

Government Tests of Antitoxin. After the product has been packed for shipment and is ready for use, samples are removed from the lot and tested by two government experts working independently. The antitoxin is not approved for use until the results of these final tests are compared and known to be satisfactory.

Amount Used. In mild cases only 3,000 units of antitoxin may be used, while in severe attacks as many as 20,000 are sometimes employed. Antitoxin is now frequently administered as a protective treatment to children who have been exposed to the disease, and in such cases, from 500 to 1,000 units are used as a dose. The material is injected by means of a sterile hypodermic needle into the loose tissues beneath the skin.

The Effectiveness of the Antitoxin Treatment. The curative value of this treatment is well recognized, and there is no doubt that the death rate from diphtheria has been greatly reduced as a result of its use. In some large cities where records are available, the rate for the ten years following the adoption of the antitoxin treatment was only one-third to one-half of what it was during the preceding ten-year period. At present, *antitoxin is looked upon by health authorities as almost a certain remedy for diphtheria, if it is given in time and according to approved methods.*

The Treatment Practically Devoid of Danger. Antitoxin, as it is given to-day, rarely results in any serious injury to the

patient. Sometimes a slight rash or a pain in the joints may follow, but this generally is not of much consequence and soon disappears. Before the modern methods of production of antitoxin were perfected, there was some reason to question its general use, for sometimes deadly bacteria or other impurities caused fatal accidents. To-day, the cases of injury are exceedingly rare in comparison with the very large number of treatments that are given throughout the country.

Precautions in Times of Epidemics of Diphtheria. When a case of diphtheria breaks out in a family, the patient should be isolated and only those who nurse him should be allowed in the sick room. Those tending him should use the greatest care to avoid the possibility of droplet infection, especially if the patient coughs. The hands should be washed frequently and kept away from the mouth. The bed linens and clothing of the patient should be handled with care and disinfected by boiling as soon as removed from the sick room. Very often small doses of antitoxin are administered to other members of the family, especially to the children.

SMALLPOX

Smallpox in Early Times. Smallpox was one of the great plagues of the ancient world. Before vaccination came into general use as a preventive measure, literally millions of people were swept off by extensive epidemics that spread over vast areas of territory, sometimes involving continents. Towns, cities, and fertile regions were often rendered uninhabitable.

During the years immediately following the introduction of the disease into Mexico, it is estimated that three and a half millions, a large portion of the inhabitants of the country, were swept away by smallpox. In the eighteenth century, it is stated that fifteen millions perished in twenty-five years from this disease in Europe alone, to say nothing of other thickly populated regions of the world. Certainly no disease in all the history of mankind has excited more fear and dread than smallpox.

Smallpox To-day. A remarkable change has taken place dur-

ing the last hundred years. Smallpox is not looked upon with great dread and extensive and deadly epidemics no longer occur in civilized countries. The appearance of a case of smallpox in a modern community is the signal for action, and, as a result, the disease is checked, often without the loss of a single life and sometimes without serious suffering. All this must be attributed largely to the practically universal practice of vaccination. No one who impartially studies available scientific data can doubt that this preventive treatment has been the chief means by which the human race has been freed from this plague.

The Contagious Character of Smallpox. Before vaccination came into general use, smallpox was probably one of the most contagious of all diseases. This, together with its fatal character, was responsible for the dreadful outbreaks of the past centuries. It is stated by an authority that ninety-five per cent of the unvaccinated who had not had the disease were susceptible to the deadly types, at the time when vaccination was first introduced. At the present time, in civilized countries, smallpox seems to be less contagious than formerly as well as less serious, probably because of the long use of vaccination. It should be understood, however, that even now, prompt action on the part of health officials in enforcing vaccination and quarantine is essential in controlling outbreaks.

Cause of Smallpox. Although smallpox is readily controlled to-day, the causative organism has not yet been identified with any degree of certainty. Some hold that a protozoan is the cause of the disease, while others assert that certain bacteria are concerned. It may be possible that more than one organism is involved.

Transmission of Smallpox. The fact that the causative organism is not known with certainty complicates the problem of ascertaining how the disease is scattered. It is probable, however, that *personal contact*, more or less direct, is largely responsible. As with other diseases known to be scattered in this way, isolation of the patient, quarantine, and cleanliness about the sick room are very effective in controlling outbreaks.

Discovery of Vaccination. During severe epidemics of smallpox in England in the latter part of the eighteenth century, it

was noted that dairy maids frequently escaped infection. Investigations showed that there was an important relation between smallpox and the disease known as cowpox, which people sometimes contracted from cattle. Finally in 1798, it was established by Jenner, through carefully planned inoculation experiments, that a person who had had cowpox was practically immune to severe attacks of smallpox. The news of the discovery reached Boston, and the medical authorities in that city carried on a series of experiments from which they drew this conclusion: "Cowpox is a complete security against the smallpox."

Early Use of Vaccination. The early practices connected with vaccination were extremely crude and were attended with considerable danger. Not infrequently, disastrous results followed because of impure vaccine or of infection from other sources. Nevertheless, so definite was the protection afforded, that the practice spread rapidly throughout the civilized world. To-day vaccination is almost universally employed in civilized countries as the first step to be taken in controlling outbreaks of smallpox.

Preparation of Vaccine in Former Years. In former years, the virus used for vaccination was often transferred directly from arm to arm, either through the pus from the sores or by means of the dried scabs. In either case there was great danger, not only from outside sources, but also from the transfer of blood diseases. These crude practices were later discontinued, and the vaccine used for human inoculations was obtained from young cattle. Although this was an improvement over the earlier practice, there was still great danger from tetanus and other germs, as well as from infection of open sores. Such a practice could not be safe until modern bacteriology pointed the way. It is not to be wondered at, that serious results all too frequently followed in the wake of vaccination during these early years.

Modern Vaccine. The vaccine of to-day is a much safer product than that used a generation ago. It is still obtained from healthy young cattle that have been inoculated with cowpox; but the precautions observed in its production and purification are such that it is extremely rare for a sample of virus to cause trouble. On the

whole, there is no longer the slightest reason for objection to the use of vaccination, except in the rarest cases where some physical peculiarity may interfere. In these cases the advice of a competent physician should be sought.

Vaccination Practically Devoid of Danger. Vaccination, as it is practiced at the present time by competent physicians, is practically devoid of danger. Conclusive evidence indicates that the prejudice existing in some quarters against this practice is entirely unwarranted. Vaccination is no more dangerous than is any minor wound in which the surface of the skin is slightly broken. It is true that sometimes a very sore arm results, but this is generally due to neglect in caring for the wound, rather than from the effects of the vaccine itself. Open sores are always a menace if not properly cared for, and the slight injury from vaccination is no exception to the rule.

Tetanus and Vaccination. Tetanus, or lockjaw, is the most important complication that may arise from the use of vaccine. Since the tetanus germs are widely scattered and enter the body through wounds, vaccinations seem to offer excellent opportunities for the contraction of this disease. Carefully kept records during recent years, however, show how rarely this happens. The United States Health Report for July 16, 1915, states that following the use of thirty-one million doses of virus in this country during the ten years ending 1914, there occurred only forty-one cases of this disease. Moreover, the evidence indicates that in these cases the tetanus germs were not in the virus, but gained entrance through the neglect of the wounds. Records also show that in five hundred eighty-five thousand vaccinations in the United States army and navy not a single case developed. More than a generation ago thirty-two million people were vaccinated in Germany, and only about one in five hundred thousand died as a result of complications that could be attributed definitely to this practice. More recently, American authorities in the Philippines vaccinated three and a half millions without a single death, or even serious complications, as a result.

Value of Vaccination as a Means of Protection from

Smallpox. More than a hundred years of trial have demonstrated beyond doubt that vaccination is extremely effective in checking epidemics of smallpox and in reducing the death rate from this disease. Records from various countries in different parts of the world show the reduction in mortality resulting from vaccination. During the years 1886 to 1889 inclusive, the average yearly death rate in Sweden, Ireland, Scotland, and Germany, where compulsory vaccination was practiced, was from one to three and a half per million of inhabitants; while during the same period in Switzerland, Belgium, Russia, Austria, Italy, and Spain, where there were no laws of this nature, the death rate per million ran from eighteen and a half in Switzerland to more than five hundred in Austria and Italy, and up to nine hundred sixty-three in Spain.

In Germany, where compulsory vaccination has been enforced very rigidly in recent years, smallpox has almost disappeared. During the first ten years of the present century there were only three hundred and eighty deaths from smallpox in Germany, while in England and Wales, where vaccination was not so general and where the population was much smaller, there were over four thousand deaths. Previous to the World War, when Germany had a vast army, smallpox was almost unknown among its soldiers, only two deaths from this cause occurring in more than forty years.

Vaccination in the Philippines by the American authorities, following the Spanish-American War, likewise reduced the mortality from this disease to a marked degree.

Death Rate of Vaccinated and Unvaccinated. A comparison of the death rate from smallpox among the vaccinated and unvaccinated is interesting. In the London Smallpox Hospital from 1836 to 1856, the death rate per hundred cases among the unvaccinated was thirty-five, while among the vaccinated it was seven; in Vienna Hospital about the same time, the death rates were thirty, and five, respectively; in France, where sixteen thousand cases were observed, the rate was sixteen among the unvaccinated and one among the vaccinated. Many more examples of a similar nature are on record.

Relation of Cowpox to Smallpox. It is held by authorities

at the present time that cowpox is caused by a form of the same organism that produces smallpox. It has been shown that cattle inoculated with the virus from a typical case of smallpox develop a disease similar in all respects to cowpox. It is highly probable that the germ, upon entering the system of the cow, becomes modified to such a degree that it is no longer able to cause smallpox when introduced into human beings. The fact that cowpox protects one from contracting the more serious disease is a strong indication that the two organisms are essentially similar.

How Vaccination Protects from Smallpox. A vaccination that "takes" confers *active immunity* against smallpox. The organisms that cause cowpox stimulate the cells of the body to produce substances that will destroy the germs of smallpox, if the individual is exposed to it. Although the real nature of these protective substances is not clearly understood, they are known to be effective and they appear to remain in the system and retain their effectiveness several years.

Revaccination. Every few years revaccination is advised to determine whether the individual is still immune to smallpox. If vaccine that is known to be potent fails to "take," it indicates that the protective substances are probably still present. Several trials are sometimes made, to make certain that failure to "take" is not due to poor vaccine or to some other external condition. If vaccination "takes," it indicates that the person would have contracted smallpox had he been exposed.

COLDS

The Importance of Colds. The diseases generally referred to as colds are much more serious than most people suppose them to be. Sometimes colds are of a very mild nature and interfere but little with one's general condition; but at other times contagious forms appear, and the results are serious. The direct results of colds, even of the most severe types, are usually not to be feared so much as their far-reaching effects upon the general health and the resistance of the body to other diseases. A cold that con-

tinues for several weeks should be looked upon with concern; for under these conditions, the vitality of the body is sure to be lowered, and the way opened for the most serious consequences. Everyone should understand that *it is far from safe to neglect a cold.*

Cause of Colds. Although the diseases usually referred to as colds vary much in their nature and their effects upon the body, doubtless a large majority of them are caused by living organisms. The types that are contagious and which spread rapidly through the community are certainly brought about in this way. This fact is indicated by the similarity between the behavior of these diseases and that of others known to be caused by germs. The precaution of quarantine, taken to check other germ diseases, applies equally well to contagious colds.

Personal Contact and Colds. The germs causing colds are scattered practically always through direct contact. People thrown together in crowded rooms, cars, and the like, during times of epidemics, are likely to become exposed. This is certain to be the case if infected persons present are coughing. Germ-laden droplets of mucus float in the air in such places for a considerable time, and are practically certain to gain access to the throat and nasal passages of those present, and to cause infection if conditions are favorable for the development of the organisms.

Colds and Open Air. There is but little danger, comparatively speaking, of contracting a cold in the open air, even in the presence of those suffering from this disease. This is due to the great rapidity with which particles of mucus are scattered by the natural currents of air which are practically always present out of doors. When sweeping a rug, one notices the marked difference between the behavior of particles of dust floating in a room and of those floating in the open air. In the first case, the particles float for an indefinite time and settle very slowly, while in the second, they are scattered at once and disappear. During epidemics of contagious colds, indoor crowds should be avoided.

Entrance of the Germs into the Body. The germs that cause colds enter the system through the mucous membranes of the

throat and nasal passages. If, for any reason, these tissues are injured, or have lost their resistance to bacteria, the germs may enter and develop here, giving rise to the well-known symptoms of the cold. On the other hand, if the throat tissues are perfectly healthy the germs cannot enter, and infection is avoided. It should be kept in mind, then, that there are two factors to be considered with reference to the contraction of colds: 1. The avoidance of germs; 2. The avoidance of all influences that tend to reduce the general vigor of the body or the resistance of the tissues of the throat and nasal passages.

Conditions That Reduce the Resistance of Throat Tissues.

It is seldom possible under the ordinary conditions of life to avoid all danger of coming into contact with the various germs involved in colds. It is probable that some very common organisms are concerned in the more prevalent types of colds. As a consequence, it becomes necessary to pay careful attention to the conditions that make it possible for the germs to gain a foothold in the body. The most important of these are congestion of the tissues of the throat and nasal passages, diseased tonsils, and adenoid growths.

Cause of Congestion. The distribution of blood in the organs of the body is influenced by various conditions. Active organs generally demand larger blood supplies at the expense of the inactive. For instance, during physical exercise more blood flows to the muscles, during the process of digestion a greater amount flows to the digestive organs, and during mental work, a larger supply is sent to the brain. Of more importance from the standpoint of congestions, however, is the effect of the changes of outside temperature upon the distribution of the blood in the skin and underlying tissues and in the internal organs, especially the throat region.

Effect of Temperature upon the Blood in the Skin. When the body is warm, the skin and underlying tissues are well supplied with blood. When the surface is cooled, this supply is automatically forced inward and the amount in the organs of the interior is increased. The skin and underlying tissues have a large blood capa-

city. Therefore, if these regions become suddenly chilled, large quantities of blood will be forced into the internal organs, tending to produce congestion there. This is especially true if chilling occurs while the muscles are inactive and, consequently, cannot take care of the excess.

Physical Conditions and Congestions. If the body is in excellent physical condition and "hardened to the cold," as we say, serious congestions are not likely to occur. But if the individual is in a weakened state at the time of chilling, there is great danger of congestion and consequent loss of resistance in the throat tissues. If under these conditions the bacteria of colds are present, infection is very likely to result, and a cold develop.

Time To Treat a Cold. The most effective time for treatment of a cold is at the very beginning; that is, when the congestion first appears in the throat, and before the bacteria get a foothold. It is generally an easy matter to recognize a congested condition of the throat. The tissues become more or less swollen and raw, and often there is an excess of secretion from the membranes of the nasal passages.

Importance of Relieving Congestions. Many of the most effective remedies for checking colds at this early stage consist in relieving the congested condition of the throat tissues. Among these are hot foot baths, hot drinks taken just before retiring and hot baths followed by profuse sweating. When the congestion is relieved, the tissues of the healthy throat quickly regain their normal resistance and the danger of contracting a cold is greatly decreased. The congestion of the tissues of the throat, does not constitute a cold, but is simply a predisposing factor.

Diseased Tonsils and Throat Trouble. The tonsils, which are composed of porous tissue, are located in the sides of the throat passage near the base of the tongue. When enlarged, they sometimes project into the cavity so that they may be seen. At other times, they may be almost completely buried in the surrounding tissues and practically invisible without the aid of instruments. Diseased tonsils are a serious menace to health; for they become the portal of entry for germs not only of colds, but also of various

other diseases. Bacteria gain access to the crypts or cavities often present in the interior of these organs, develop there, and permanently reduce the resistance of this region. (Fig. 138.)

Diseased Tonsils and General Health. Not only do diseased tonsils make it easy for germs of colds, tonsilitis, and other throat infections to gain entrance, but they may also become a genuine source of danger through harboring other bacteria. These bacteria may affect the system in general by the poisons they produce, and thus give rise to trouble in the joints, and in the heart and other organs.

It is generally agreed by authorities that the only really effective treatment for diseased tonsils is their removal, an operation that has become very common during recent years, and one that has proved advantageous in preventing troubles in the throat and other organs.

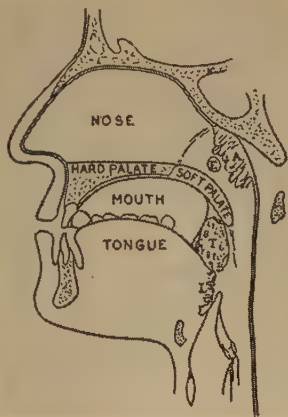


FIG. 137.—TONSILS AND ADENOIDS

A. The adenoid or third tonsil. T. One of the faucial tonsils. L. The lingual tonsil. E. Eustachian tube, connecting the naso-pharynx with the ear. (From *Adenoids and Tonsils* by Coolidge, Harvard University Press. By permission)

Enlarged Adenoids and Health. Adenoids are growths that occur in back of the throat cavity somewhat above the soft palate, which generally hides them from view. In young children, they are of considerable size and may have some function; but as time passes, they gradually become smaller. Quite frequently adenoids become diseased and increase in size, not only in young children, but also in older people, and interfere seriously with the general health. The throat passage in the region of the adenoids is not very large, and any great increase in these tissues very soon interferes with the passage of air through the nose. As a result, the habit of mouth breathing becomes established. The tissues of adenoids, when unhealthy, apparently bear much the same relation to the contraction of colds as do diseased tonsils. The

removal of adenoids by the surgeon is now regarded as most desirable from the standpoint of general health.

General Health and Colds. The importance of a vigorous, resistant body as a safeguard against colds and related diseases can scarcely be overestimated.

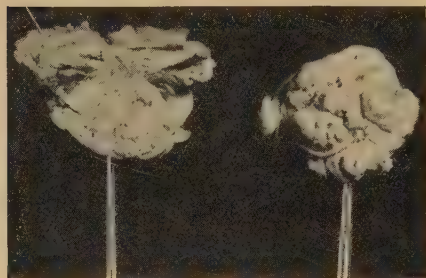


FIG. 138. — DISEASED TONSILS

Left — Tonsil cut through the center and spread open to show the interior. *Right* — Surface view. (Original)

A vigorous condition not only protects one from contracting colds, but also tends to prevent the disease from causing serious trouble, if the germs do enter the tissues. Many of the important predisposing factors to colds — such as the vitiated air of poorly ventilated rooms, overwork, exposure, and excessive fatigue — find their explanation in the fact

that they materially reduce the general vitality of the body so that the normal resistance to germs becomes weakened. *If the system is run down and in a weakened condition, no amount of precaution can entirely make up for the deficiency.*

WOUNDS AND OPEN SORES

Danger of Open Sores. An injury that breaks the surface of the skin should always be looked upon as a possible source of serious trouble, even though it may seem to be trivial at the time. So common are such occurrences that many, who do not recognize the danger of wounds of this nature, neglect them until it is too late to prevent infections that too often result disastrously.

It is by no means rare for the scratch of a pin, an abrasion by cinders, and the like, if neglected, to give rise to blood poisoning or erysipelas. The germs of lockjaw, one of the most feared of all human diseases, may enter through wounds that, at the time, are considered of no consequence. *Every open wound, no matter how*

slight, should receive careful attention until the healing process is well on the way, and all danger of infection is past. "Safety first" applies to these conditions with great force.

Care of Wounds. Proper treatment of a minor wound, as a rule, involves but little expense or trouble, and is such a simple task that any intelligent person should be able to do the work successfully with but little instruction and practice. A wound of serious nature, one that is torn and difficult to cleanse or extensive enough to require stitches, should be cared for by a person trained for this work. It is a most serious error in judgment for the average untrained person to attempt to take the place of the physician simply to save the fee, when the injury is of a nature to demand expert service. Saving in this way often results in conditions that may in the end be very expensive.

Bacteria and Open Sores. The presence of bacteria in open wounds is by far the most important condition likely to interfere with healing. Much of the inflammation, swelling, and soreness, and practically all pus formation, as well as the serious diseases mentioned above, are due to these organisms. The problem of caring for minor wounds virtually consists in keeping bacteria from entering, or, if they are already present in the injury, in preventing their development.

The healthy, unbroken epidermis, in general, is an excellent protection from germs of all sorts. There is evidence, however, that occasionally they pass through hair follicles and sweat glands, or possibly through the epidermis itself, and give rise to pimples, boils, and other eruptions; but this is not very common.

Kinds of Bacteria That Infect Wounds. There are three general types of bacteria that are likely to gain access to wounds and cause trouble: 1. Ordinary pus-producing forms, such as those most generally found in boils and abscesses; 2. Bacteria of erysipelas and closely related forms; 3. Tetanus germs, the most feared of all.

Pus-forming Bacteria. These bacteria are practically always present upon the skin, or just beneath its surface, where they are protected more or less by the loose outer layers of the epidermis. It is most difficult to remove these without special care. Washing

is a great aid, but the germs in the deeper layers of the epidermis are scarcely reached by this method. Strong disinfectants that possess penetrating power are necessary in order to free the skin of all bacteria.

It is so difficult to rid the hands of all bacteria that sterile rubber gloves are now quite generally used by surgeons when performing operations where infection is likely to occur.

Erysipelas Type of Bacteria. These bacteria are also spherical forms, but they are not so likely to be present as the common pus-forming type. However, they are of rather frequent occurrence, and when they gain a foothold, may cause much more serious results than follow when the infection is due solely to the ordinary pus-forming group. Before modern surgical methods were developed, erysipelas and related troubles were the bane of hospitals, and to-day these diseases are guarded against with the utmost care.

Blood Poisoning. The unchecked development of either of the types of bacteria mentioned above may apparently give rise to the dangerous condition known as septicemia or "blood poisoning." Such may take place in almost any wound when the general resistance of the body is at a low ebb. In ordinary wound infections, the development of the germs is limited to a definite area, generally extending not far from the original injury. In "blood poisoning," the organisms scatter more or less extensively through the surrounding tissues and are carried in the blood, where they multiply and thus produce a most dangerous complication.

Tetanus Germs. The germs of tetanus are the most dangerous form infecting open wounds. They are not abundant on the skin as are the common pus-forming types, but are widely distributed in nature. They are abundant in the intestines of horses and some other animals, where they seem to subsist as saprophytes upon the organic refuse there. Consequently the soil about stables or wherever horses are found, is often infected. For this reason, wounds that are contaminated by materials from the soil are likely to be dangerous, especially where the flesh is more or less torn and difficult to cleanse.

Tetanus bacteria differ in several important particulars from most other disease producing organisms.

1. *Tetanus germs are anaërobic.* That is, they are able to develop only under conditions where free oxygen is excluded. This fact is of the most far-reaching importance with regard to the treatment of open sores. It is obvious that bacteria in general must be prevented from entering wounds, but at the same time, since these dangerous forms can grow only out of contact with air, it is to be kept in mind that *air-tight dressings should not be used.*

2. *Tetanus germs form spores,* and consequently are very resistant. As has been pointed out in the previous pages, most disease organisms are comparatively easy to destroy by heat, light, drying, and chemical disinfectants; but such is not the case with these forms. Even boiling temperature is not surely fatal to the spores unless applied for a prolonged period. They are apparently able to live in the dry condition in dust or other materials for a long time. These facts explain why tetanus germs are so dangerous in connection with antitoxins and other serums, and why it is so essential to guard with the greatest care against such contamination.

3. *Tetanus germs develop best in contact with foreign matter,* such as particles of dust, earth, or paper. Dirt coming into contact with wounds, then, not only carries germs into the injury, but also brings about the conditions under which tetanus bacteria may best develop. Wounds made by gunshots, firecrackers, and dirty objects from the soil are apt to end in lockjaw, unless promptly and carefully looked after. In these cases there is often great difficulty in removing the particles of foreign material, and if at the same time, the wound closes, so that some part of it, at least, is out of contact with the air, the conditions suitable for the development of tetanus germs result.

Tetanus Germs in the Body. The germs of tetanus do not scatter to any great extent through the tissues, but are generally localized at, or very near, the point of entrance, where they multiply. The germs produce a deadly toxin that travels over the nerve

trunks, and upon reaching the central nervous system, gives rise to the well-known symptoms of the disease.

Prevention of Tetanus. The tetanus antitoxin prepared much in the same way as that used in diphtheria, is of little value as a curative agent, but as a preventive it is extremely effective. Prophylactic doses are now commonly given when there is any danger of tetanus developing, as in Fourth of July injuries, gunshot wounds, and the like. In the Great War, tetanus antitoxin was used very widely and was effective as a preventive measure even in the worst type of wounds, and under the most adverse conditions. In fact, so successful was the treatment that, after the use of antitoxin became general, tetanus ceased to be a serious menace in the hospitals of France.

Treatment of Open Wounds. The treatment of minor injuries in which the surface of the skin is broken, may be looked upon as consisting of three rather definite steps: 1. The *cleansing* of the wound, 2. The use of *antiseptics*, and 3. The *dressing*.

The Cleansing of the Wound. The prompt removal of all foreign matter from the wound, whether slight or of a more serious nature, is the first and probably the most important step to be taken in the proper treatment of such injuries. A wound made by a clean sharp knife free from dirt need cause no worry, especially if it bleeds freely. One made by some object that crushes or tears the flesh and carries foreign materials into the broken tissues, is always dangerous.

When the bleeding is profuse and there is no serious contamination of the injury, the blood coming from the deeper portions often is sufficient to carry out most of the foreign matter. In most cases, however, the bleeding is not sufficient to cleanse the injury properly, and other methods must be employed.

An abundance of pure water poured gently upon the wound, or applied by means of a soft, clean cloth is a very satisfactory way of washing out foreign matter. A weak solution of carbolic acid, mercuric chloride, or some other antiseptic chemical is employed to cleanse the wound. Grain alcohol is also an excellent agent for this purpose.

Antiseptics. When the wound is cleansed as thoroughly as possible, some weak antiseptic substance is generally applied to prevent the development of any bacteria that may still be present. *Alcohol* is sometimes used for this purpose. *Turpentine* is very effective for ordinary cuts and scratches. *Tincture of iodine* is extensively used where there is considerable danger of serious infection. Weak solutions of *carbolic acid*, *corrosive sublimate*, and a number of others, sold at drug stores with directions as to their use, answer the purpose well.

The tendency at present in caring for ordinary wounds is to use comparatively weak antiseptics rather than the stronger chemicals of former days. A substance that is active enough to destroy bacteria in a wound, is very likely to injure seriously the exposed living tissues, so that the healing process may not take place properly. In some cases, to be sure, it may be necessary to cauterize the wound with strong agents that destroy the tissues as well as the bacteria, but this treatment is very rare. The ideal antiseptic is one that will prevent bacterial development and yet will not injure the living tissues.

The Dressing of Wounds. Two things should always be kept in mind in binding up a wound: 1. Bacteria and any sort of dust or dirt should be prevented from entering; 2. The dressing should permit free access of air. Sterile cotton gauze which may be obtained at any drug store meets these requirements and is very widely employed for this purpose. The loose cottony texture of several thicknesses of this material allows plenty of air to enter and yet excludes bacteria. Sometimes a layer of absorbent cotton is used with good results for this purpose.

RABIES

Dogs and Rabies. The dreadful disease known as *rabies*, or *hydrophobia*, is transmitted almost exclusively through bites of "mad" dogs or other "mad" animals. There is no cure for the disease after definite and well advanced symptoms appear. The mortality in such cases is extremely high. *Pasteur's treatment*,

which is very effective and, moreover, the only means known for preventing rabies, should be resorted to as soon as possible after the bite from a rabid animal.

Transmission of the Disease. The virus of rabies is transmitted in the saliva of the rabid animal, and gains entrance to the tissues of the human body through the wounds made by the animal's teeth, or through open sores or other breaks in the skin, if infected saliva is brought into contact with them.

The *virus* apparently *travels over the nerves* toward the brain, and it is not until this organ is reached that the symptoms of the disease appear in the individual. The rate of movement over the nerves is slow, a fact which explains the long period, from one to several months, that elapses between the bite and the appearance of the symptoms. This fortunate circumstance allows time for the preventive treatment to be given.

Preliminaries to Treatment for Rabies. The preliminary step to be taken in the Pasteur treatment is to determine with certainty whether the animal concerned is "mad." Such evidence may be perfectly apparent from the characteristic symptoms of the disease in dogs, such as frothing at the mouth and spasms, but it sometimes is more difficult to obtain. It is known that a dog may transmit the disease several days before it shows definite symptoms of rabies; moreover, in certain cases, known as *dumb rabies*, the characteristic "mad" stage may be entirely absent.

If a person is bitten by a valuable dog that is apparently well, the best procedure is to confine the animal for ten days or two weeks under close observation. If, at the end of this time, the dog is in good health, no bad results need be feared so far as rabies is concerned, for if it had been present the animal would have shown the symptoms.

In the case of a stray dog or one that is likely to get away so that it cannot be watched, the safest procedure is to kill the animal and send the head to a Pasteur institute. Here specialists examine the brain and are able to determine with accuracy whether or not the dog was rabid. What has been said of dogs, relative to rabies, applies as well to cats and various other animals that might go mad.

Nature of the Treatment. The Pasteur treatment, when applied in time, renders the patient immune to rabies. This result is accomplished through hypodermic injections of graduated doses of virus obtained from the spinal cords of rabbits. At the beginning of the treatment a very weak type of virus is used, but at intervals of a day or two, stronger and stronger doses are administered. The time required varies in different cases, but the full treatment generally occupies about three weeks. The gradual increase in the strength of the virus administered, enables the body to acquire resistance sufficient to overcome the virus that has entered the system through the bite of the rabid dog or other "mad" animal.

The varying samples are obtained by transmitting the disease from a mad dog through series of rabbits, a procedure which increases the strength of the virus. Finally the spinal cords containing the strongly infectious material are removed and dried. The drying gradually weakens the virus. Portions of these cords are preserved for use from time to time.

The Effectiveness of the Pasteur Treatment. The Pasteur treatment is the only specific method known to science that is of value in combating rabies and statistics prove beyond a doubt that it is extremely effective when applied in time. In fact, many thousands of lives have been saved through its use during the last half century. The discovery and development of this treatment by the immortal Pasteur is universally looked upon as one of the greatest achievements of all time in the science of preventive medicine.

Former Treatments for Rabies. The Pasteur treatment should, in no sense, be confused with the worthless and absurd "mad stones" of former years. These were reputed to be porous stones which, in some mysterious way, would cling to wounds made by a rabid animal until the poison was drawn out. Another treatment that was sometimes practiced consisted in cauterizing the wounds with strong chemicals. This treatment is no longer relied upon by the well informed.

The Control of Rabies. The *muzzling of dogs* is very effective in the control of this disease, by preventing both its spread among

lower animals and its transmission to man. In this country, the chief trouble in applying this method is the difficulty of securing efficient enforcement of such regulations. In a number of European countries, rabies has almost or entirely disappeared as a result of strict enforcement of muzzling ordinances and laws. Let us hope that here the time will soon come when we likewise can blot out this disease.

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PART III — NUTRITION AND HEREDITY IN MAN

CHAPTER X

NUTRITION AND HEALTH OF THE HUMAN BODY

GENERAL DISCUSSION

Conditions Affecting Health. The most important factors that promote good health are *nourishing food, fresh air, and exercise*. The food is the most fundamental; for, if the proper materials are not present for the building up of the tissues and for the production of energy, no amount of fresh air or physical exercise can make up for the deficiency.

Inherent weaknesses of various sorts and accidents that interfere with the functioning of parts of the body also influence health. Even in these cases, the best treatment consists in good food, fresh air, and proper exercise. The same is true relative to the prevention and cure of all sorts of diseases.

Processes Affecting Food in the Body. The changes that the foods undergo in the body have a very definite bearing upon the health of the individual. The first step in the process is *digestion*, which converts these substances into forms suitable for use in the tissues. These digested products find their way into the blood through *absorption*, and are distributed throughout the body by the *circulation*. Through the process of *respiration*, or oxidation in the tissues, a certain part of the food carried to the tissues releases energy. The remainder is either employed for the building of tissue, or stored for subsequent use. The waste products produced are removed through *excretion*.

Organs of the Chest and Abdomen. (A careful study of Fig. 140 should be made in order to bring clearly to mind the relative positions of the important internal organs.) The upper portion of the body cavity, known as the *chest*, or *thorax*, is virtually surrounded by rigid walls supported by the ribs. The lower part,

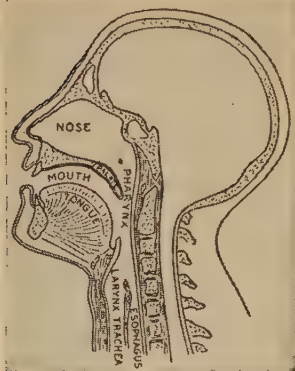
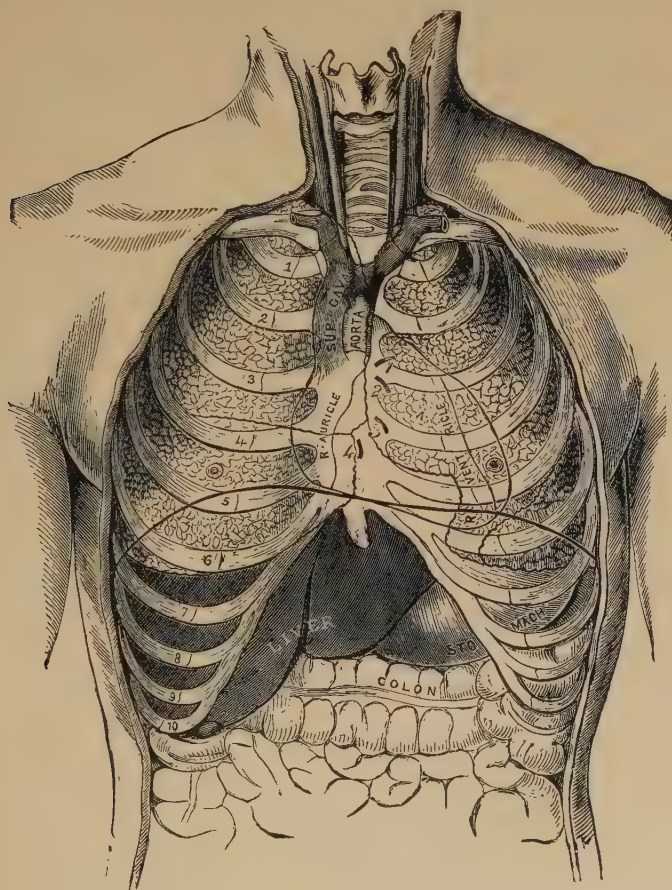


FIG. 139. — DIAGRAM OF A SECTION OF THE HEAD AND NECK, SHOWING THE UPPER PART OF THE PASSAGES FOR AIR AND FOOD (From *Adenoids and Tonsils* by Coolidge, Harvard University Press. By permission)

referred to as the *abdomen*, has elastic walls on the ventral side, composed of the skin, sheets of muscle, and other tissues, and is supported on the dorsal side by the spinal column and lower ribs. These cavities are separated from each other by a thin sheet of muscle, the *diaphragm*, which is attached to the body wall at the lower border of the ribs, and arches upward to form a dome-shaped partition. Just above, and fitting down quite accurately upon the convex surface, are the *lungs*; between these, with its tip resting almost upon the diaphragm, is the heart. The *trachea*, or wind pipe, and the *esophagus*, or gullet, enter the chest cavity from the throat region; through the former, the air enters the lungs, and through the latter, the food passes to the stomach. The great artery, known as the *aorta*, that carries the blood from the heart, curves upward and back from the center of the heart, and passes downward near the vertebral column.

Just below the diaphragm, fitting into the dome-shaped cavity, are the *liver* on the right, and the *stomach* toward the left. The *bile duct*, which conducts the bile from the liver, reaches the small intestine a few inches from the lower end of the stomach. Beneath the stomach and against its walls, is the *pancreas*, the duct of which reaches the small intestine at the point where the bile duct enters. The *small intestine*, a narrow coiled tube which receives the food from the stomach, occupies a large part of the lower

portion of the abdominal cavity. The small intestine conducts the food materials to the *large intestine*, or *colon*, to which it is connected at a point in the lower right hand side of the abdominal



1. Pulmonary Orifice
2. Aortic Orifice

3. Left Auriculo-Ventricular Orifice
4. Right Auriculo-Ventricular Orifice

FIG. 140. — FRONT VIEW OF THE THORAX

The ribs and sternum or breast-bone, are represented in relation to the lungs, heart, and other internal organs. The appendix is not shown in the figure. (From Colton's *Physiology, Experimental and Descriptive*, page 106)

cavity, just within the projection of the right hip bone. From this point, the colon passes upward to the waist line, crosses to the left side of the body, and then turns downward, taking an S-shaped form in the lower part of the abdominal cavity. The *appendix*, the organ concerned in appendicitis, is normally a small coiled structure just below the junction of the small and large intestine. The *kidneys*, two in number, are situated at the back of the abdominal cavity near the waist line.

DIGESTION

Digestion in Man and Plants Compared. Digestion of food in the human body is a process fundamentally the same as that found in plants, which has been discussed on page 65. In the animal, however, the enzymes are produced by groups of specialized

cells known as *glands*, while in plants they are formed in various tissues. In animals, also, there are special tubes, or *ducts*, that carry the digestive fluids to the place where they are to act upon the foods. The enzymes in the two seem to be practically identical both in their chemical nature and in their mode of functioning.

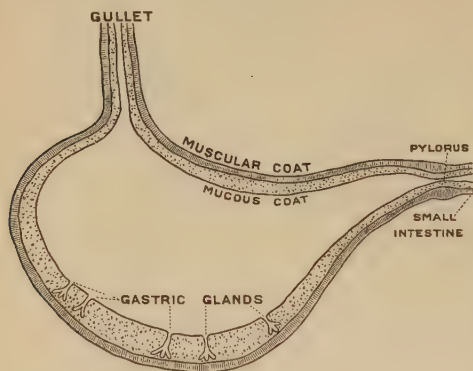


FIG. 141. — LONGITUDINAL SECTION OF THE STOMACH, SHOWING THE GASTRIC GLANDS IN POSITION (Dorsal view. Mucous coat unduly thickened) (From Colton's *Physiology, Experimental and Descriptive*, page 213)

Production and Composition of Saliva. The saliva in man is produced by several pairs of glands situated in the tissues surrounding the mouth cavity. The ducts from these empty the fluid into the mouth at several points. The saliva is composed largely of water in which

is dissolved the enzyme, known as *ptyalin* (diastase), together with a certain amount of mucus, and some other substances.

Action of Saliva. The mucus of the saliva serves to make the food a smooth, pasty mass. More important than this is the action of the *ptyalin*. This enzyme starts the digestion of the starch, and seems to play an important part; others, found in the intestines, complete the changes in this carbohydrate that finally result in the production of simple sugar. (Fig. 36.)

The process of starch digestion is complicated, consisting in a number of definite changes that follow one another until the final products appear. When acted upon by the enzymes, the starch soon disappears and simpler, more soluble substances, known as *dextrines*, are produced. These give rise to a complex sugar, which in turn is reduced to glucose, the form suitable for use in the tissues. Dextrines are familiar to everyone in toasted bread, and in many of the brown breakfast foods.

Mastication. Thorough chewing of the food is necessary for good digestion; for the longer the materials are held in the mouth, the more saliva is mixed with them. This is of great value in digestion, for the saliva continues to act for a considerable time after the food reaches the stomach.

Thorough chewing grinds and crushes the food into fine particles, so that the digestive juices can more readily reach all parts and act more promptly. Furthermore, thorough mastication of the food compels one to eat more slowly, and consequently there is less danger of overloading the stomach. Too rapid eating is a tendency that large numbers of people would do well to overcome.

Condition of the Food in the Stomach. The stomach is an elastic organ, the size of which varies with the amount of food present. At the beginning of a meal the organ is often quite small, but it becomes much larger as more food is taken. If a semi-solid food is eaten, such as bread, meat, or potatoes, a mushy mass is formed, which extends from the entrance at the larger end of the stomach down towards the smaller, or *pyloric*, end. The food remains in this general condition until it becomes mixed with the gastric juice through the movements of the stomach walls.

Production of Gastric Juice. The gastric glands permeate the inner mucous coat of the stomach, and throughout the entire surface, myriads of tiny tubes open on the interior. Through these the gastric juice is distributed over the mass of food held within.

Movements of the Stomach. As the gastric juice is poured out upon the mass of food, the muscular outer layers of the stomach walls are thrown into a series of wave-like contractions. These arise at the larger end, and progress slowly downward to the pyloric end, wave following wave in unbroken succession. This movement serves well to mix thoroughly the gastric juice with the *outer portions of the mass of food*. As this becomes semi-liquid in nature, it collects in the pyloric end of the stomach, where it remains until expelled into the small intestine.

Gastric Juice; Its Composition and Action. The gastric juice consists largely of water and two enzymes, *pepsin*, and *rennin*, as well as some *hydrochloric acid* and other substances. The pepsin acts upon protein and appears to bring about certain preliminary changes and thus prepares the way for the enzymes of the pancreatic juice. The rennin coagulates milk, but the purpose of this process is not clearly understood. The hydrochloric acid aids the action of the pepsin.

Manner in Which Food Leaves the Stomach. As the semi-liquid materials collect in the pyloric end of the stomach, the muscle that closes the orifice into the small intestine opens, allowing a small amount of the more liquid portion of the food to pass through. Then the muscle again closes the opening. The food that has just entered the intestine passes on quite rapidly, leaving an empty section near the stomach. Again the muscle relaxes, permitting another jet of food to enter, and again it closes the orifice. This process is continued until the stomach is empty. By the time that the last portions of the food have left the stomach, the first that passed out may be practically through the small intestine.

The value of this distribution of the food throughout the small intestine is that it enables the entire length to function, instead of confining the action to a relatively small portion, as would be the case if the food left the stomach in a continuous stream.

Drinking Water during the Meal. It was formerly thought that large quantities of water taken during a meal would dilute the gastric juice in the stomach and thus interfere with its action; but this is not the case. An abundance of water taken with the meal is beneficial to health. This must not be interpreted to mean that the food may be moistened and washed down with water without being properly masticated, for such a practice would be harmful.

Passage of Water through the Stomach. Water taken into the stomach when it is empty or when it contains semi-solid food, passes on into the small intestine in a very short time. The water does not mix with the food, as was formerly thought to be the case; on the contrary, as soon as it reaches the stomach, it passes around the outside of the mass and on into the small intestine. It is probable that some of the semi-liquid foods are carried along with it, but this does no apparent harm. Since large quantities of water are beneficial to health, the habit of drinking freely at meals is advantageous.

Effect of Emotional States upon Digestion. Everyone is familiar with the fact that certain emotional states, such as worry, sorrow, excitement, and anger, tend to result in loss of appetite. On the other hand, happiness, pleasure, and good news have the opposite effect, providing they do not cause profound emotional disturbance. With many people, simply the thought of objectionable things takes away much of the enjoyment of eating, and even causes attacks of nausea.

Relation of Emotions to the Secretion of Saliva and Gastric Juice. Well cooked beefsteak, spiced pickles, and various other foods are often said to "make the mouth water." In such cases the pouring out of saliva into the mouth is most noticeable when the individual is hungry and craves the food. Even the thought of eating is sometimes sufficient to produce the effect. The sight or odor of appetizing food in some way results in the stimulation of the nervous mechanism thus causing the flow of saliva. Such effects are generally referred to as "*psychic secretions*." Doubtless this type of secretion plays an important rôle in digestion in the human body. (The student should definitely apply

these facts and those immediately following to the hygiene of feeding.)

Similar relations exist regarding the gastric juice. It has been demonstrated in experiments upon dogs that the sight or odor of meat, when the animal is hungry, is followed by a pouring of gastric juice into the stomach. The same occurs when the meat is chewed by the dog but not permitted to pass into the stomach.

But when egg white is placed in the stomach of the dog while attention is centered upon something else, no such flow follows. Some foods, however, such as soup, which contain extracts of meat, seem to cause a secretion of gastric juice when placed in the stomach.

Anger and Movement of the Stomach. An important observation relative to the effect of anger upon digestion was made upon a cat. When the movements of the animal's stomach were observed by means of an X-ray machine, it was noted that while the cat was in a good humor, so to speak, the movements were regular and continuous, but when it became angry and struggled, the wave-like motions ceased at once.

Doubtless observations upon the lower animals indicate in general what takes place in the human body under similar conditions. We may conclude, therefore, that *emotional states have far-reaching effects upon digestion in man.*

Small Intestine; How Supported. The small intestine consists essentially in a long muscular tube supported in the folds of a thin membrane, the *mesentery*, which in turn is attached to the tissues at the back of the abdominal cavity. This permits free movement of the intestine, which materially aids in the passage of food through it. Horseback riding, running, jumping, and in fact any vigorous exercise, will cause the loosely supported folds to move about and thus aid digestion.

Movement of Food in the Small Intestine. Besides the movements just described, there are the contractions of the muscular coats of the small intestine itself, which serve to keep the food mixed with the digestive fluids, and to force it along towards the large intestine. The food requires but a few hours to reach the large intestine. The rapidity with which it passes through the small

intestine prevents serious bacterial development in this part of the digestive tract.

Passage of Materials through the Large Intestine. In the large intestine the movement is much slower, and it is here that the residues of the food are likely to decompose and cause trouble.

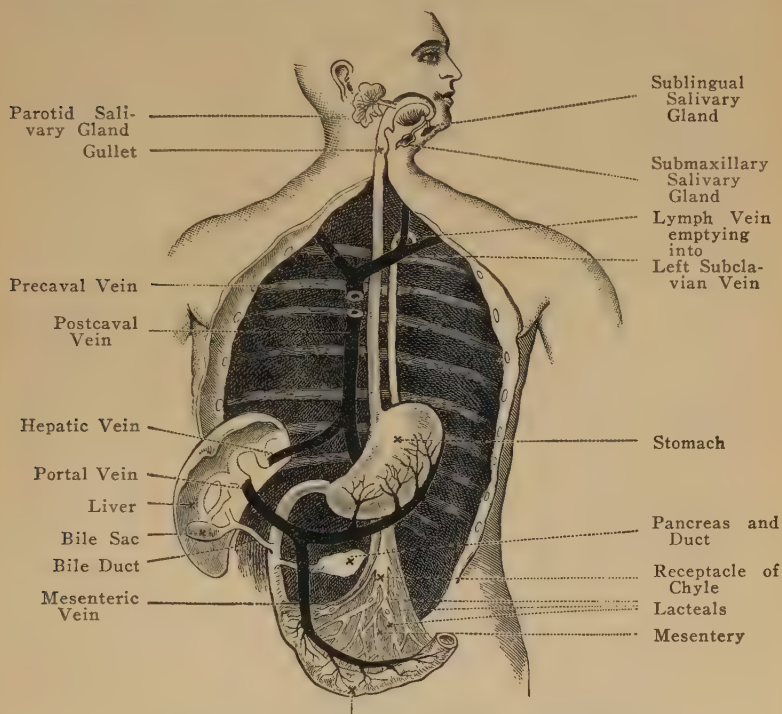


FIG. 142.—DIAGRAM OF THE ORGANS CONCERNED IN THE CONVERSION OF FOOD INTO BLOOD
(From Colton's *Physiology, Experimental and Descriptive*, page 225)

The drying out of the food and the formation of poisons through bacterial action sometimes affect the body in a serious manner. The residues of the food, together with various substances from the liver and other organs, collect in the S-shaped portion of the lower intestine, where they are held until passed from the body. If these

substances lie in the large intestine too long, as is sometimes the case in biliousness and other troubles, serious results may follow.

Completion of Digestion. The digestion of the food is completed in the small intestine. The pancreatic juice, with some help from the *bile*, secreted by the liver, and the *intestinal juice*, produced in the walls of the small intestine, complete the reduction of the nutrients to the final forms suitable for absorption into the blood and for use in the body.

Absorption in Intestines. The carbohydrates and proteins are taken into the blood directly, through the capillaries of the *villi*, innumerable microscopic projections that cover the interior surface

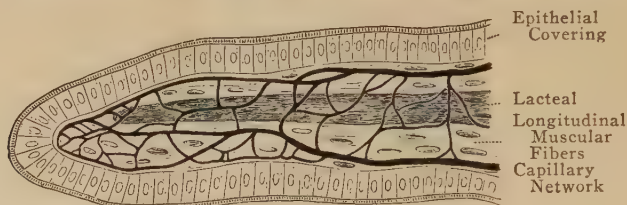


FIG. 143. — INTESTINAL VILLUS, MUCH MAGNIFIED (From Colton's *Physiology, Experimental and Descriptive*, page 224)

of the small intestine. The fats are taken into special tubes within the villi, and reach the blood by way of the *thoracic duct*, a large tube that arises in the intestinal region and connects with a vein in the left side of the chest cavity not far from the heart. Little absorption other than that of water normally takes place in the large intestine.

Value of Bulk in the Diet. In order for the foods to pass readily through the intestines, it is necessary that they should occupy considerable space; in other words, they should have sufficient *bulk*. If most of the food is digested and absorbed, the movement of the residue consisting of the bile and other substances, is likely to be difficult, as it is frequently of a mucilaginous nature and tends to adhere to the walls of the intestines. If coarse particles of indigestible materials, such as the skins of fruits and the cellulose tissues and fibers of green plants, are present in abundance, they

aid in keeping the intestines in proper condition. The greater part of such substances as sugar, pure starch, milk, and tender meat, is digested and absorbed, and consequently these foods leave small amounts of residue.

Physicians often prescribe special foods in cases of digestive disturbance, in order to increase the bulk in the intestines. Wheat bran and purified agar are helpful in these conditions. Stockmen also recognize the necessity for bulk when they feed oat straw or corn fodder to cattle and horses.

Indigestion. Biliousness and attacks of indigestion are now often referred to by the more descriptive term, *auto-intoxication*, a word which means self-poisoning. What really happens in many such cases is as follows. A person overeats, or what amounts to the same thing, takes a quantity of food into the intestine, usually protein in nature, that for some cause or other is not digested. This material may reach the large intestine without causing trouble, but here, where the movement is not rapid, the mass of residue becomes compact and ceases to advance. Decomposition sets in, resulting in the formation of poisonous substances which may find their way into the blood and affect various parts of the body, notably the digestive organs themselves. Possibly the nervous mechanism of the intestines and other internal organs also becomes involved in the general disturbance.

As a result of these abnormal conditions, the functioning of these organs is hampered, and the food that is eaten is not digested, but added to the mass already decomposing in the large intestine. The poisons formed are probably passed into the blood, the matter gets worse and worse, and what is called a "*vicious cycle*" is the result. This condition is relieved by the stimulation of the digestive and excretory organs, and by suitable regulation of the diet. It is often advisable to cease eating entirely for a time, in order to permit the elimination of the decomposing food from the intestines.

Appendicitis. Appendicitis is the inflammation and often the enlargement of the appendix, which in severe cases may even rupture. The latter condition is serious; for the myriads of bacteria that are always present in the intestinal contents, may then escape

and become widely scattered throughout the abdominal cavity. This is the reason physicians advise an operation for the removal of the appendix as soon as the trouble is diagnosed. If such an



FIG. 144. — DISEASED HUMAN APPENDIX

The organ is many times larger than is normally the case. The cut is one-half natural size. (Original photograph)

operation is performed before there is danger of rupture, it is not a very serious matter.

Bloating. Gas formation in the digestive tract is often the result of bacterial action. Generally, this occurs in the large intestine, but at times it takes place in the stomach and small intestine. The

bloated condition of the abdominal organs, in certain cases of indigestion, is commonly due to this accumulation of gas.

The result of this bloated condition is sometimes alarming, because of its *effect upon the heart beat*, which is explained by the relative positions of the intestines, the stomach, and the heart. The presence of the gas greatly enlarges the abdominal organs, thereby causing an upward pressure upon the diaphragm, and consequently upon the heart, a condition which interferes with its regularity of action. Many cases of irregularity of heart action disappear when the digestive disturbance is relieved. Another result, either of gas formation, or of the enlargement of the stomach due to a heavy meal, is "shortness of breath." This is also a result of the upward pressure upon the diaphragm, which makes it difficult to take in a full breath.

Exercise and Digestion. Vigorous exercise is advantageous to the health in general, but it is particularly beneficial to digestion. Through the ages, man has been an *active creature*. Modern civilization, however, has caused vast numbers of people to forsake active

pursuits for employment where little or no vigorous muscular exercise is demanded. Certainly we should not be surprised that digestive disturbances, as well as many other ills, are more prevalent now than they were in pioneer days.

One of the most important factors underlying good digestion is the prompt passage of the food through the intestines, and the regular elimination of the waste substances. The muscular walls of the intestines are helpful in bringing about this result; but in the majority of cases, these movements alone are not sufficient. This is indicated by the prevalence of digestive disturbances among those who lead inactive, sedentary lives.

Exercise and the Movement of the Intestines. If we recall that the intestines are supported in the folds of membrane, and that consequently they may move about with great freedom, we can readily see how all sorts of vigorous bodily activities affect them. Strenuous exercise, such as athletic sports and hard labor, aids in the movement of the intestines, and the deep breathing employed during these activities is also beneficial.



CIRCULATION

Functions of the Blood. The blood is the common carrier in the body. It distributes oxygen and food substances to the tissues, and removes carbon dioxide and other wastes. It also carries those substances which are active in protecting the body against disease, and other materials known as internal secretions, which are important in the functioning of various organs. The blood stream also distributes to all parts of the body the heat produced by oxidation.



FIG. 145. — A RUPTURED HUMAN APPENDIX REMOVED IN AN EMERGENCY OPERATION

The dark spot near the bottom is an opening into the interior. (Original photograph)

Composition of the Blood. The blood consists largely of a liquid known as the *plasma*, in which float innumerable cells referred to, in general, as the *corpuscles*. These are of two kinds: the numerous *red* corpuscles, which carry the oxygen, and the less numerous *white* corpuscles, which are active in protecting the body

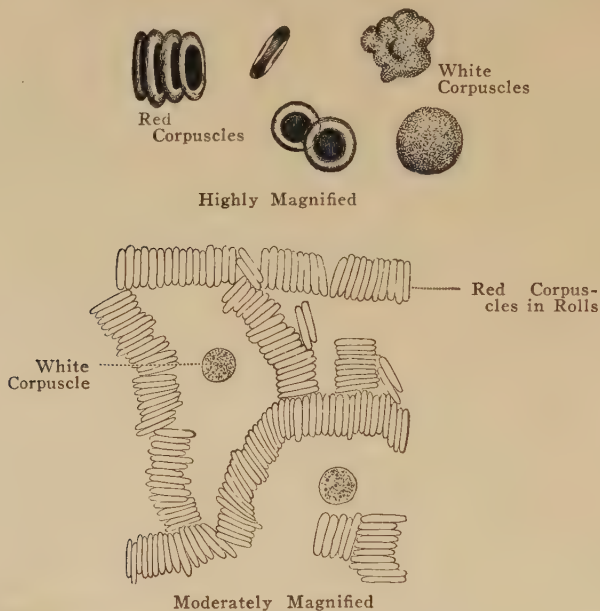


FIG. 146. — RED AND WHITE CORPUSCLES OF THE BLOOD (From Colton's *Physiology, Experimental and Descriptive*, page 95)

against germs, and in removing certain foreign substances, such as materials used in stitches in surgical operations. (Page 243.)

Circulation of the Blood. The blood is carried through tubes, known as *blood vessels*, that ramify throughout the living parts of the body. They are of three types. The *arteries*, thick-walled and imbedded in the tissues, generally near the bones, carry the blood *from* the heart; the *veins*, thin-walled and often situated near the surface, carry the blood *toward* the heart; and the *capillaries*,

microscopic tubes with very delicate walls, form extensive networks in the tissues. The capillaries *connect* the arteries and the veins, and, at the same time, bring the blood into close proximity to the living cells of the body.

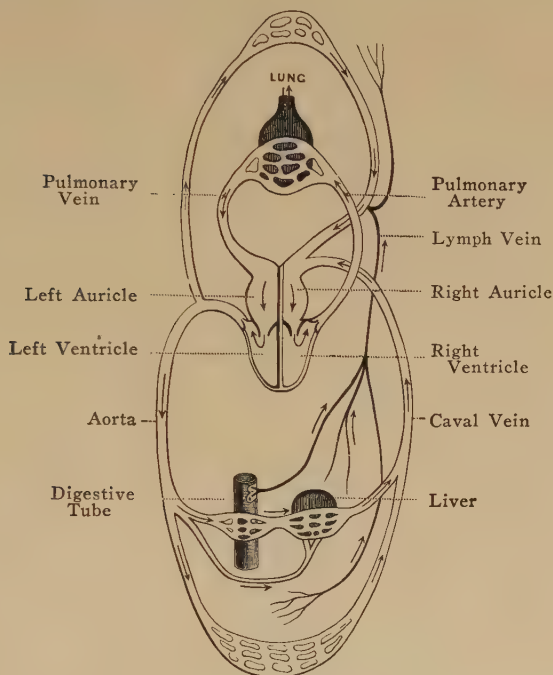


FIG. 147.—PLAN OF CIRCULATION (Dorsal view.) (From Colton's *Physiology, Experimental and Descriptive*, page 85)

Near the heart, the arteries are large and consist of a few main trunks; but farther away, these divide and subdivide, finally giving rise to the minute capillaries. The veins near the heart likewise are large and few in number, and are formed through the union of the smaller veins that carry the blood from all parts of the body. The veins differ from the arteries in having numerous *valves* dis-

tributed at irregular intervals, which allow the blood to flow only toward the heart.

The Heart as a Pump. The heart consists essentially of two muscular pumps, placed side by side. One of these, situated on the right, forces the blood through the lungs, and back to the left side; the other, on the left, sends the blood out through the aorta to all other parts of the body, and back to the right side. The blood, then, in a complete circuit of the body, passes through the heart twice. The four sets of valves in the heart and the arteries leading from it, are so adjusted as to compel the flow to take place as indicated above.

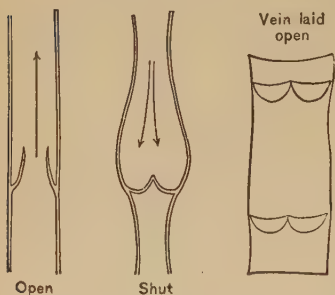


FIG. 148. — VENOUS VALVES
(From Colton's *Physiology, Experimental and Descriptive*, page 83)

Exercise and Blood Flow.

Besides the pumping action of the heart, there are other influences that assist the circulation of the blood. The most important of these are *muscular activity* and the *respiratory movements*. The hardening of the muscles during contraction causes intermittent pressure to be exerted upon the veins, which tends to force the blood toward the heart. The vigorous intake of breath draws the blood into the chest cavity from the veins without; this likewise tends to increase the flow toward the heart.

Exercise also results in *increase in the rate of the heart beat*, which can be measured by means of the *pulse*. If the pulse is counted while a person is sitting, then while he is standing, and finally, after he has exercised vigorously, a great increase in the rate of the heart beat will be found. It follows that severe exercise is dangerous in cases of organic trouble with the circulation, such as leakage of the valves or hardening of the arteries. Under such conditions, the acceleration of the heart rate increases the pressure upon the various parts of the circulatory system to such an extent that it may result disastrously.

The Origin of the Lymph. As the blood passes through the capillaries, some of the liquid portion escapes through the walls into the irregular spaces in the tissues, and is then known as *lymph*. This is similar to the blood in composition, but does not contain red corpuscles. The openings among the tissues are known as *lymph spaces*. By examining a thin slice of freshly cut beefsteak,

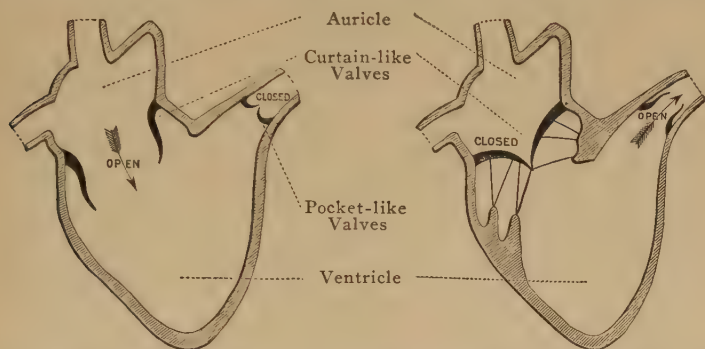


FIG. 149. — DIAGRAM OF THE HEART SHOWING THE ACTION OF THE VALVES
(From Colton's *Physiology, Experimental and Descriptive*, page 74)

one can get an idea of the extent of these spaces, and also of the general character of the lymph, which oozes out and moistens the wrapping paper. From these tissue spaces, the lymph is drained off by the lymph capillaries, and finally reënters the blood.

Function of Lymph. The lymph bathes all of the living cells of the body. The various substances from the blood pass through the lymph into the tissues, and the waste products formed in the tissues pass through it into the blood. The lymph occupies a very important place in the mechanism of the body. If it fails to circulate in the tissues, the exchanges just referred to cannot readily take place, and serious results may follow.

Movement of Lymph. The lymph is not pumped through the tissues in the way that the blood is forced through the body by the heart. The movement depends partly upon the *activity of the muscles*, which, during contraction, exert pressure upon the tissues, thus causing the lymph to circulate. There is also some force

exerted upon the lymph in the tissues by the "seepage" from the blood in the capillaries.

Massage. The rubbing and kneading of the various parts of the body by the hands is referred to, in general, as *massage treatment*. When the body is at rest and the muscles are inactive, the

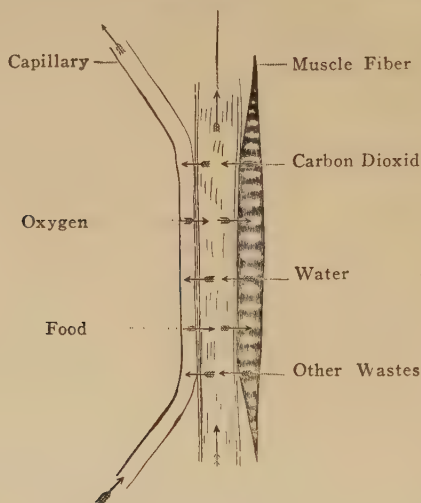


FIG. 150. — RELATION OF BLOOD AND MUSCLE

(From Colton's *Physiology, Experimental and Descriptive*, page 101)

flow of the blood in the capillaries and the movement of the lymph in the tissues, are certain to be sluggish. At times, when exercise of the body or of a group of muscles is inadvisable or impossible, massage is substituted for muscular activity. In such cases, this treatment is of great value.

The "rub down" of the athlete, the kneading of a sore muscle, the rubbing of a sprained ankle, and the application of many liniments and ointments, where the substance is "rubbed in," are examples of massage. Probably the chief benefit from the applica-

tion of various substances to the skin, is a result of the massaging rather than of the character of the ointments themselves. However, there is value in improving the surface of the skin by applying such substances as lotions for chapped hands, which soften the epidermis and make it more pliable.

RESPIRATION AND EXCRETION

Respiration in Man. Respiration is fundamentally the same in man as in plants. The process consists in the oxidation of the food substances, directly or indirectly, in the living tissues, and the releasing of energy. In man and in the other higher groups of animals, special organs are necessary to provide oxygen for the tissues and to eliminate the waste materials. The *lungs, air tubes, and air passages*, specially adapted for this purpose, are called the *respiratory organs*.

Oxidation in the Tissues. The air is taken into the lungs, where it furnishes the oxygen to the blood and receives carbon dioxide to be carried out of the body. The oxygen is carried through the circulatory system to the tissues, where it diffuses into the lymph and thence into the living cells, in which it comes into contact with the food substances. Here oxidation takes place and *energy is released*. Some of this energy is utilized in the form of heat, some in the form of motor energy, and some in the production of living substance.

Excretion of Waste Substances. The body is freed from the waste products of respiration and of other processes that take place in the various organs, by means of *excretion*. The carbon dioxide is excreted almost entirely through the lungs; and the nitrogenous wastes, resulting from the decomposition of proteins, are removed through the kidneys. The water formed by oxidation is similar to that which we drink; hence it is not necessary to discuss it here. The skin is not an excretory organ to any great extent, although traces of waste substances are present in the perspiration.

Necessity of Fresh Air. Abundance of good fresh air is one of the important factors underlying vigorous health. No single

condition, except poor food, perhaps, is more depressing than the breathing of foul air. If a person remains for a time in a crowded room where the ventilation is inadequate, discomfort, dullness,

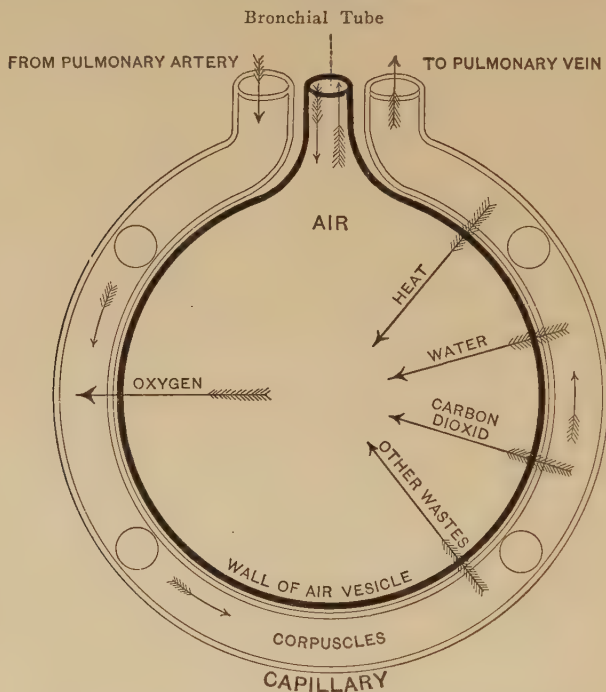


FIG. 151. — EXCHANGES BETWEEN THE AIR AND THE BLOOD IN THE LUNGS

(From Colton's *Physiology, Experimental and Descriptive*, page 129)

headache, and even fainting may result. These marked and immediate effects certainly are sufficient to emphasize the importance of fresh air. It is no wonder that those who live more or less permanently under such conditions are very susceptible to tuberculosis and to all sorts of other diseases, and that they become physically weakened in many other ways.

Need for Ventilation. *Early ideas.* Just how the vitiated

air of a crowded room produces the marked effects mentioned above is a question of great importance. Formerly, it was held that the evil effects were due to the lack of oxygen and to the presence of an excessive amount of carbon dioxide. It was also thought that poisonous organic substances in the air were an important factor. These explanations have not stood the tests of recent, carefully controlled experiments.

Seldom, if ever, in ordinary habitations, or even in crowded schools and churches, is the oxygen supply so reduced as to cause trouble, nor the carbon dioxide so abundant as to be definitely injurious. In fact, the amount of the latter would have to be increased many times before evil effects would be noticeable. Likewise, it seems that the traces of organic substances present in expired air are not really the cause of the bad effects, although they may intensify the discomfort.

Modern view. The injurious effects of air in poorly ventilated rooms are now considered to be due largely to the *presence of too much moisture*, and at the same time, to *too high a temperature*. It is well known that these conditions result in marked discomfort even out of doors where the air is free and always in circulation, as in the case of very warm, moist weather in the summer. It is clear then why the conditions so rapidly become oppressive in a poorly ventilated room, where there is little circulation, and where the air breathed out is at the temperature of the body and is practically saturated with moisture.

Effects of Deep Breathing. Some of the advantages of deep breathing have been discussed; namely, its influence in *aiding circulation*, and *its effect on digestion*. Another of its effects that is of great value to health is a more *thorough exchange of air in the lungs*. So important is this, that many physical exercises used in the gymnasium and in the school room have as their aim the formation of the habit of deep breathing.

The Amount of Air in the Lungs. The capacity of the lungs for air varies greatly in different individuals because of differences in the size of the chest and in the habits of breathing. While at rest, a person of average size inhales and exhales, in an ordinary

quiet breath, from about twenty to thirty cubic inches of air; but about one hundred and twenty cubic inches more may be inhaled through extra effort. After the ordinary breath is exhaled, about

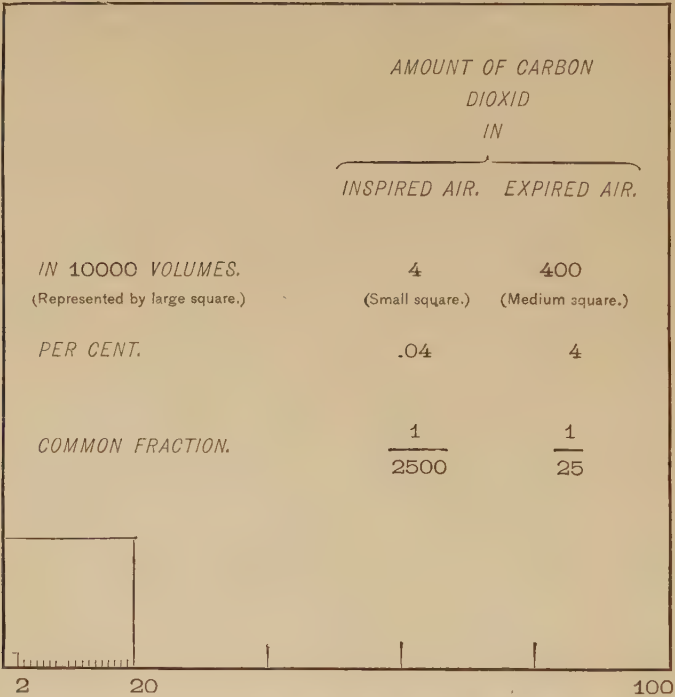


FIG. 152. — AMOUNT OF CARBON DIOXIDE IN INSPIRED AND EXPIRED AIR

(From Colton's *Physiology, Experimental and Descriptive*, page 127)

one hundred cubic inches more can be forced out. There remain in the lungs about one hundred cubic inches that cannot be forced out.

Ordinary Breathing and Lung Capacity. Since the air capacity of the lungs of an average individual is something like three hundred and thirty cubic inches, and since only thirty cubic inches are inhaled and exhaled at an ordinary breath, only one-

eleventh or one-tenth of the full chest capacity is used. Moreover, this includes the air that does not reach the air cells of the lungs, but simply passes in and out of the air passages. Another fact of

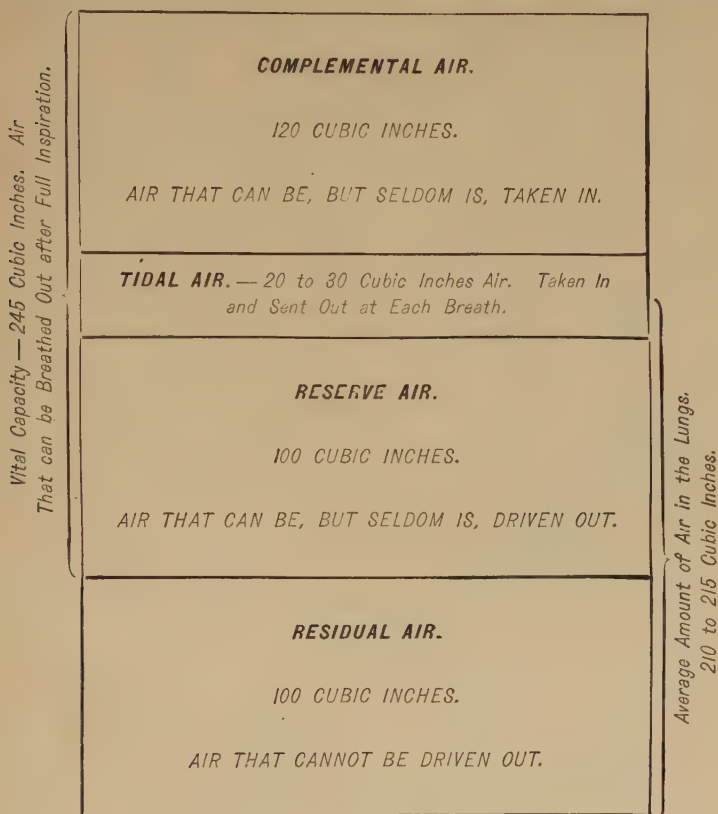


FIG. 153. — DIAGRAM OF LUNG CAPACITY

(From Colton's *Physiology, Experimental and Descriptive*, page 118)

importance is that the larger portion of the ordinary breath comes from the most accessible parts of the lungs rather than from the outlying regions. Ordinary breathing, then, is certainly not adequate to ventilate the lungs, or, in other words, to displace the foul air of the lungs with fresh air from without.

Habits of Breathing. Deep breathing, in which comparatively large amounts of air are inhaled and exhaled at each breath, is certainly valuable from the standpoint of health. By this means, the fresh air reaches the deeper parts of the lungs and the foul air is much more efficiently carried out. Upon rising in the morning, and often through the day, it is a valuable practice to go into the open air and breathe deeply a number of times, thus thoroughly ventilating the lungs.



FIG. 154.—CARBON DIOXIDE IN THE FIRST PORTION OF THE EXPIRED BREATH AS COMPARED WITH THE LAST PORTION

Left — Clear lime water. *Center* — Lime water through which a definite portion of the air first expelled from the lungs has been passed. *Right* — Lime water through which the same amount of air last expelled from the lungs has been passed. (Original)

The question of determining the diet is one of the most important and, at the same time, one of the most complex problems related to health.

Knowledge concerning the diet is valuable because, if the facts

The amount of carbon dioxide in the first portions of the expired breath, as compared with that in the last few cubic inches exhaled, indicates the great efficiency of deep breathing in ridding the lungs of this gas. The first part of the breath, when blown through a tube into lime water, often used as a test for carbon dioxide, produces but little effect, while the final portion rapidly causes an abundant precipitate, which indicates the presence of large amounts of carbon dioxide.

THE DIET

Importance of Attention to the Diet. The amount and kinds of food suitable for a person are extremely variable, depending upon the type of work done by the individual, his physical state, and the climatic conditions.

are known, the average individual can choose his food to suit his needs. The problem is rather difficult, however, because of the complex relation of the food to the body. Most subjects of this type, such as the purification of the water supply, the disposal of sewage, and the treatments for various diseases, may be left to the specialist. With the subject of the diet, on the other hand, everyone is directly concerned, and he must, in the main, determine for himself what he is to eat.

Amount of Food Required. The quantity of food required by an individual depends very largely upon the amount of energy needed by the body for muscular action, and for the maintenance of constant temperature. The man at hard manual labor needs a much larger energy supply than the one who sits at a desk all day. Likewise, much more energy in the form of heat is required to keep up the body temperature during the winter than during hot weather. The demand for food to maintain the living tissues, on the other hand, differs comparatively little in the case of the active manual laborer and in that of the indoor worker. With rapidly growing children, however, and with adults who are recovering from excessive loss of weight, the demand for food as building material is higher.

Definitions. A *calorie*, as used in regard to diet, is the *amount of heat required to raise the temperature of one kilogram (2.2 lbs.) of water one degree Centigrade*. The amount of energy obtained by the human body through the oxidation of a gram of dry starch is 4.1 Cal.; of dry protein, 4.1 Cal.; and of fats, 9.3 Cal. These figures should be remembered.

Determination of Food Values in the Body. The value of food in the body is estimated in terms of calories. The following facts will serve to show why this can be done. 1. A gram of dry carbohydrate, for example, when completely oxidized in the chemical laboratory, so as to produce carbon dioxide and water, gives off four and a tenth calories of heat. 2. It is known that a gram of carbohydrate, when oxidized completely in the body, gives off the *same* amount of energy as is produced in the laboratory. 3. It is also a well-known principle of physics that *one calorie of heat, when transformed into motor energy, will perform a definite amount*

of work. Hence the number of calories required by the body to do a certain amount of work may be calculated; and since the number of calories available in the nutrients is known, the weight of these nutrients that are necessary in the diet may be determined.

Nutrients and Food Values. The proportions of carbohydrate, fat, protein, water, indigestible materials, and salts in the various foods, are always the basis for determining the amount and kind of food to be included in a diet. This analysis is necessary, because the foods, as we eat them, are mixtures of the various nutrients and differ much in content, and because the different nutrients have special uses in the body. When the composition of the food is known, it is an easy matter to determine the value of each nutrient and, consequently, the value of the food as a whole.

The Amount of Carbohydrates in the Diet. The group of carbohydrates, including the various sugars, such as cane sugar, milk sugar, glucose, and others, and the starches from various sources, should constitute by far the largest portion of the diets of mature people. It is recommended that the actual dry weight of carbohydrate in the diet should be from two and a half to three times the weight of the proteins and fats combined.

Value of Carbohydrates in Diet. Carbohydrates, especially starches, should make up a large portion of the diet because of several well-recognized facts:

1. That carbohydrates are the best adapted to provide the large amounts of energy needed by the human body is indicated by their ease of digestion, and by the manner in which they are stored in the liver in the form of glycogen, to be held until needed by the tissues. Moreover, when they are oxidized in the tissues, the waste products, carbon dioxide and water, are comparatively harmless, and easily excreted or otherwise taken care of.

2. If carbohydrates are taken in larger quantities than can be digested and absorbed, the residues in the intestines do not bring about the formation of poisons through bacterial action, as is the case with proteins. On the other hand, if digested carbohydrates are absorbed in larger quantities than the body needs at the time, the excess is simply stored for future use.

3. **Carbohydrates**, of all the nutrients, are by far the cheapest source of energy; for they compose the larger part of our low priced foods, such as cereals and potatoes. Energy from round steak of average price costs fifteen or twenty times as much as does the same amount obtained from wheat flour. The protein foods, calorie for calorie, are much more expensive, generally speaking, than the products rich in carbohydrates. The fats, although less expensive than proteins, are not so well fitted as the carbohydrates to supply energy.

Sugar Compared to Starch as Food. In general, carbohydrates in the form of starch are very much better in the diet than large quantities of sugar. Although all starches are converted into sugar, through digestion, before they are absorbed and used in the tissues, this does not indicate that large amounts of sugar may be eaten without injury to the health. A certain amount of sugar, when mixed with other substances or eaten during the meal, can be safely taken care of by the body; but when excessive quantities in practically pure form, as in candies and other sweets, are taken into an empty stomach, the ultimate results are detrimental to health.

Sugar in Large Amounts Injurious. Starch must be digested before absorption can take place. Since the process of digestion continues for hours after the meal, the sugars formed are passed into the blood so slowly, that they can be taken care of by the liver and the tissues. But when a large amount of sugar is taken into the intestines, it seems to be absorbed too rapidly, and the excess amount cannot be disposed of. The result may be the appearance of sugar in the urine, a condition that certainly should not occur.

Candy before Meals. Sugar or candy taken into the empty stomach is likely to "spoil the appetite," as we say, and thus prevent the full enjoyment of the food. Children who eat candy before meals are sometimes undernourished; for they do not eat sufficient food to meet the needs of the body.

Fats in the Diet. Fats, which are very concentrated food substances that furnish large quantities of energy when oxidized,

produce more than twice as many calories per gram as either carbohydrates or proteins do. Fats, however, are not well adapted to provide a large supply of energy; for the human digestive system is usually not able to take care of them in large quantities.

A certain amount of fat, when taken with other foods, is of value for the production of energy, and can be disposed of to advantage by the body. In fact, authorities always recommend a considerable amount of fat in the diet; but the quantity suggested is much smaller than that of the carbohydrates, varying from a tenth to a sixth of the total dry weight of the food.

There is not much danger of eating too great a quantity of the foods that are largely composed of fats, because of a general dislike for most of these substances. Pure fat meats or greasy foods, as a rule, do not appeal strongly to the appetite. Some fats however, such as butter, are much more palatable. A large part of the fat taken in the diet is mixed with the other nutrients, as in pastry and fried foods.

Proteins in the Diet. Of all the nutrients, the proteins are by far the greatest source of trouble when taken in excessive amounts. This is due to the fact that, when undigested and left in the intestines, they bring about conditions that interfere with the normal action of these organs. Again, when used for energy in the body, they produce the nitrogenous excretory products, some of which are very poisonous if not removed promptly from the tissues. Notwithstanding all this, a certain *amount of protein is absolutely necessary in the diet; for this nutrient alone can furnish the materials that repair and build up new living substance.*

The Amounts of Protein and Other Nutrients in the Diet. There is considerable difference of opinion as to the proper amounts of the various nutrients that should be present in the diet. The following is recommended, by a leading authority, as the composition of an average daily diet for a medium sized man doing a moderate amount of physical work: carbohydrates 500 grams, fats 56 grams, and proteins 118 grams (Voit). These are weights of water-free substances. The amounts, as given above, are increased in cases of great physical exertion, and are reduced in cases of old age and of

comparative inactivity. Other authorities, though differing somewhat, give values generally not far from those quoted above.

Kinds of Protein Needed. A considerable variety of protein foods is necessary in the diet, in order to provide the various types of material needed in the building up of human protoplasm. When a given protein is digested, it is broken down into certain simple compounds, sometimes referred to as "building stones." The number and kinds of these substances vary much in proteins from different sources. Those from the gluten of wheat, for example, are quite different from those of fish or of lean beef. In the formation of the living substance of the human body a certain definite assortment of these simple compounds is needed, and, consequently, proteins from a number of sources are required to provide the necessary types. A simple protein, such as gelatin, furnishes a small assortment of digested products, and is therefore entirely inadequate, when used alone, to nourish the body; while the proteins of milk and of other substances are much more successful in this respect.

Protein as a Source of Energy. It has been pointed out that carbohydrates and fats are the chief nutrients used for the production of energy; but proteins are also employed for this purpose in the human body. The proteins which are absorbed into the blood and are not used for building up the tissues, are broken down into nitrogenous waste substances, on the one hand, and sugar, on the other. The waste materials are removed from the blood through the kidneys, and the sugar is either stored or oxidized in the tissues, like that derived from carbohydrates. When large amounts of protein are used to produce energy, excessive work in eliminating the poisonous substances is thrown upon the kidneys. A large *excess of protein in the diet*, even when it is digested and absorbed, *is to be strongly discouraged*.

Protein Often Used in Excess. One of the most frequent errors in the average diet is an excess of protein. It is not at all uncommon — in fact, it is the rule in many hotels and restaurants — to serve far too much protein, in the form of meats, as compared with the amount of carbohydrates. In the home, there is also a tendency, very strong at times, to eat largely of the nitrogenous

foods. This is practically always true in big dinners, where two or even three or four kinds of meat are served. When so much protein is eaten that it cannot be digested and absorbed, the residues in the large intestine are likely to become a source of trouble and to result in auto-intoxication, as was pointed out on page 297.

Formation of Fat. Fat may be formed from any one of the nutrients. Carbohydrates are looked upon as the most important in this respect, mainly because very large amounts of them can be utilized in the diet. The fats, doubtless, contribute directly to this end; but since they are generally taken in relatively small quantities, they cannot be the chief originators of fats in the body. When taken in considerable amounts, the proteins also may contribute to the store, through the sugar formed in their decomposition.

Excess Weight and Reduction. Overweight, due to the accumulation of fat, is from several standpoints detrimental to health. This is especially true in the case of middle-aged or of elderly people. Therefore various systems for reducing the weight have been devised, and many people are earnestly endeavoring to rid themselves of surplus flesh.

All satisfactory systems for reduction are based upon the fundamental truth that, in order to reduce, *more food must be used up in the body than is supplied by the diet*. In other words, the person *must exercise more and eat less*. Generally a program of strenuous activities, such as manual labor, games, gymnasium exercises, and dancing, is planned for the individual, to insure the consumption of large quantities of energy. At the same time, the diet is so limited that the intake of food is not sufficient to supply this energy; consequently, the store of fat is drawn upon, and loss of weight results.

Reduction through Drugs. The method of reducing described above is well worth the consideration of every stout person who desires to remain in good health; but the use of drugs to accomplish loss of weight is to be condemned. A drug that so interferes with the normal functions of the body that the stored fat is drained for the energy supply, certainly should not be used unless a competent physician so advises.

The Stored Food Supplies of the Body. When food is di-

gested and absorbed, the sugar is carried to the liver, where a part of it is converted into a starch-like substance, the *glycogen*, which is stored and used at a later time. Some glycogen is also found in the muscles. If the amount of food is greater than is necessary to maintain the energy supply, *fat* is formed and stored in various tissues of the body, making up a more permanent reserve supply than that of the liver.

The Maintenance of the Sugar in the Blood. There is always a small percentage of sugar in the blood, which serves to supply the active tissues with fuel. When this amount is reduced, more is produced from the glycogen in the liver. If the daily diet is sufficient to replenish the glycogen supply of the liver and prevent it from being totally consumed, the fat appears not to be drawn upon for the production of energy.

If, on the other hand, the demand for energy is so great that the carbohydrate supply of the liver becomes exhausted, the fat store is used to produce energy, and hence is diminished. In cases of severe illness or starvation, after the stored fat is exhausted, the body draws upon the living tissue itself which, as a result, wastes away. If this condition continues, death must finally ensue.

Water in the Diet. An abundance of pure water, taken at any time during the day, is of the greatest benefit to health. Most people drink too little water. Physicians probably recommend it in cases of indigestion and related troubles more than any other single remedy. The reason why water is so valuable is not difficult to explain.

1. Water is the means by which the nitrogenous wastes are carried from the body. If the supply is insufficient, the urine becomes too concentrated and the dangerous protein wastes cannot be efficiently removed from the blood by the kidneys.

2 Through the evaporation of the perspiration, the excess heat of the body is carried off, especially in warm weather and during vigorous exercise. If, at such times, the amount of perspiration is meager, the condition becomes serious. With the healthy individual, the amount of water taken into the body determines very largely the amount of perspiration excreted, and hence the amount of heat

disposed of in this way. Men sometimes work without injury in mills where the temperature is far above 100° F., provided that large amounts of water are taken. The cessation of perspiration in hot weather often results in sunstroke.

3. Probably the greatest benefit derived from the drinking of large quantities of water is the effect upon the digestion of the food and upon the elimination of the wastes from the intestines (Page 293). In order for the food to be absorbed and for the residues to pass properly through the small intestine, an abundance of water must be present. When the individual is healthy, the contents of this portion of the digestive tract usually are sufficiently moist. When there is insufficient water to keep the waste materials well moistened in the large intestine, the residues, which pass with some difficulty through this organ at best, become dry and hard, and serious results occur.

Water should be taken in quantities sufficient to provide for absorption, which occurs mainly in the small intestine, but enough should remain in the large intestine to keep the contents in a well-moistened condition. To accomplish this end, physicians often recommend three or four glasses before breakfast, and corresponding amounts throughout the day.

Vitamins. Vitamins are substances occurring in green vegetables, milk and butter, and other foods, which are known to play a very important part in the nutrition of the body. Their functions seem to be quite distinct from those of the ordinary nutrients. The vitamins have been obtained only recently in concentrated forms from the food substances in which they naturally occur, and, consequently, their chemical nature is as yet not very well understood. Nevertheless, much is known concerning their activity in the body, the foods in which they are found, and the effect upon them of certain influences, such as heat. A number of diseases and other physical defects are known to be the result of a diet deficient in these substances.

Effect of Vitamins upon the Body. Vitamins are not nutrients in the sense that they produce energy or furnish materials that build up the tissues. They produce their effects upon the functions

of the body in a way not well understood at present. If some of the vitamins are deficient in the diet, even though the other nutrients are present in abundance, normal growth and development fail to take place in the young of certain animals and, doubtless, in children also. Scurvy, certain nervous diseases, and probably rickets, have been shown to be due largely to a lack of vitamins in the diet.

Kinds of Vitamins. There are at least four definite types of vitamins now recognized as affecting human health, and recently there has appeared some evidence of a fifth. Those which were first recognized are known as *fat soluble A*, *water soluble B*, and *water soluble C*—the names indicating the solubility of the substances. All three of these, as well as the fourth, *vitamin D*, are important in nutrition, and the lack of any one of them is sufficient to produce serious effects.

The Occurrence of Vitamins. The vitamins are found in a rather wide variety of food substances. They are most abundant in fresh green vegetables, oranges, lemons, and various other fruits, milk from well-fed cattle, butter, canned tomatoes, cereals, and some other foods. In wheat and some other grains, the germs and the coats of the kernels seem to contain the largest amount of vitamins. Yeasts and cod liver oil, which are also rich in some of these substances, are sometimes recommended as a source of vitamin supply in certain diseases.

Effect of Heating and Drying upon Vitamins. The boiling temperature, especially in the presence of oxygen, rapidly destroys certain vitamins; but, with others, the effect is not so marked, although deterioration probably occurs to some extent. It is also likely that prolonged drying has destructive results. If some acid is present in the food when heated, the vitamins are not injured so readily. This, in part, accounts for the fact that canned tomatoes are so rich in these substances.

In former years, scurvy was prevalent in army prisons because of the extensive use of dry food. It is clear now why orange and lemon juice, as well as fresh vegetables, are preventives for this disease. It is also apparent why orange juice is so valuable for the young child who is fed exclusively upon infant foods, which are

prepared through various processes that destroy at least a portion of the vitamins originally present.

Vitamins in the Average Diet. There is little danger that vitamins will be deficient in the system of the average person in this country whose diet includes some green vegetables, milk, and fresh fruits. On the other hand, there is danger, especially for children, who are much more sensitive to deficiencies of this sort than adults, if the diet consists chiefly of canned and dried foods and white bread. Even though green vegetables are expensive in the winter, they may be the cheapest foods in the end, because they may prevent disease and a doctor's bill.

Tooth Structure and the Diet. Recent evidence indicates that faulty tooth structure, such as soft or non-resistant enamel, is primarily the result of improper nourishment of the child before

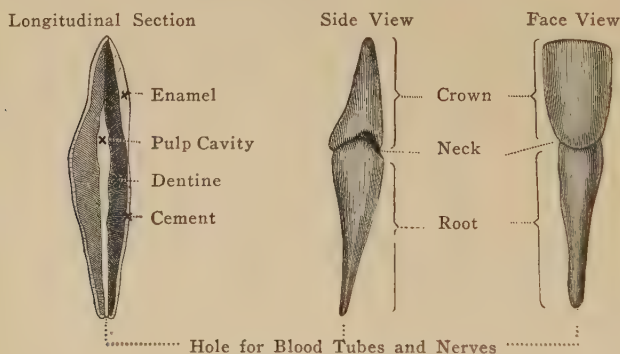


FIG. 155. — PARTS OF A TOOTH (Incisor)

(From Colton's *Physiology, Experimental and Descriptive*, page 199)

birth, or during the early years of childhood. At these periods in the child's development, the teeth are in the process of formation and are certain to be affected by deficiencies in the diet of the mother or of the child. Consequently, it is especially important that green vegetables, good milk, and fruits should be included in the diet of the mother and later in that of the child. These foods make up for the deficiencies that are certain to occur when lean meats and grains are used in excess.

Teeth and Health. Of recent years, medical men have come to realize that much ill health is due to diseased teeth. Certain forms of rheumatism and various nervous troubles that were formerly supposed to have no connection with bacteria, are now known to be caused quite often by decayed or *ulcerated* teeth.

Cause of Decayed Teeth. Cavities are caused by bacteria which develop in the food particles lodged in the teeth, and, as is common with these organisms, produce acid. These substances dissolve the enamel, leaving small cavities in which more food collects. Even if the opening through the enamel is very small, practically the whole interior of the tooth may be decayed. When the pulp cavity, which contains the blood vessels and nerves of the tooth, is reached, aching is likely to occur.

Sometimes a tooth of this type is treated, the pulp cavity is filled, and a crown is used; but this is often unsatisfactory, because certain bacteria are apt to gain access to the tissues at the root tip and give rise to ulcers, or *focal abscesses*. Extraction of teeth with infected roots is advised, rather than an attempt to treat and fill the roots and to employ the type of crowns used so freely a few years ago.

Care of the Teeth. It must be evident to everyone that the wise course to pursue relative to the teeth is to take every precaution to prevent decay from setting in. If small cavities do appear from time to time, these should be filled at once. A filling of this sort is nearly always satisfactory, and, if the work is done by a skilled dentist, lasts indefinitely. A good tooth brush should be used to keep the teeth free from particles of food. All substances that might in any way injure the enamel should be avoided. It is also well to have a thorough examination by a dentist at least twice a year.

The Drug Habit.¹ The unbounded faith in the curative power of drugs, which in many places is still quite general, is one of the outstanding erroneous beliefs relative to the problem of health. Large numbers of people seem to think that there are specific

¹ *Nostrums and Quackery* and various other publications of the American Medical Association are valuable here; address, Chicago, Ill.

remedies, in the form of drugs, that will cure all human ills, and that the only thing necessary for a cure is a prescription from the physician for the right medicine. Nothing can be farther from the truth. *The body alone possesses the power to cure itself.*

Some Useful Drugs. Some drugs and remedies are a great aid to the system in the accomplishment of a cure, such as quinine, which is used to kill the malarial germs in the blood of the patient, and diphtheria antitoxin, which is used to counteract the poison produced by the bacteria in this disease. At times, drugs are effective in stimulating the action of some organ of the body, such as a weak heart or an inactive liver. However, *the wholesale use of powerful drugs, at all times, and without the advice of a competent physician, is to be strongly condemned.*

Value of Nursing. The most marked movement relative to the treatment of disease during the past generation is the loss of faith in the curative power of drugs, and the recognition of the value of scientific nursing. This change in the attitude of leading physicians reflects the great truth, that *Nature's healing power exists within the body itself.* The chief business of the modern physician and the trained nurse is to see that such conditions as the diet of the patient, and the ventilation and temperature of the room are so regulated that the natural resistant powers of the body can assert themselves and overcome the disease.

CHAPTER XI

HEREDITY IN PLANTS AND ANIMALS

GENERAL DISCUSSION

The influences or conditions that determine the development and the qualities of plants and animals, including man, are of two general types: 1. Those due to *heredity*; 2. Those due to *environment*.

Definitions. The term, *heredity*, refers to the transmission of inborn tendencies or traits from parents to offspring *through the germ cells*. Such qualities as the presence of sugar in sweet corn, the size, flavor, and color of the Alberta peach, the speed of the grey hound, the intelligence of the shepherd dog, and musical ability in man, are examples of hereditary traits. These, and a large number of other characters in living things, may be traced from generation to generation and are found to appear under widely different circumstances and surroundings. Consequently, these characters must be due to heredity or blood relationship, rather than to external influences. Such traits are said to be transmitted in the *germ plasm*, or, in other words, in the inheritable substance that passes from generation to generation.

The term *environment*, in a broad sense, refers to all the influences or conditions, generally external, that act upon the plant or the animal during development, modifying the characters of the individual to a greater or less degree. Those conditions affecting plants, such as the character of the soil, the type of cultivation, and the water supply, and those affecting the lower animals, such as the food, the weather conditions, and training, are typical examples of environmental influences. In man, the home life, the school, the character of the associates, the religious influences, and disease, are among the important external factors that often affect the child in a marked way. Characters that are the result of environment do

not appear, except by chance, in the blood relatives that live under different external influences.

Effect of Heredity and Environment upon Development. It is sometimes difficult to determine whether a character in a plant or an animal is due mainly to heredity or to environment, for both of these influences are of importance during development. With plants, the problem is comparatively easy, but with higher animals, it is difficult to draw definite conclusions, especially in the case of mental traits in man, such as those concerned in disposition, mathematical ability, and morality. For example, the children of musically inclined parents often show ability in this line, but whether this result is due more to heredity than to the musical environment of the home, may often be questioned; for both influences may have been active during development. The same conditions arise with all sorts of human traits that slowly develop through the years of childhood.

Importance of the Problem of the Relative Effect of Heredity and Environment. If heredity is chiefly influential in determining the character of an individual, and true worth depends largely upon the inheritable traits, the family characteristics are significant and should be carefully considered. On the other hand, if environment is the main influence, then the matter of undesirable family traits is of little importance, so long as the surroundings and training are good.

This question is of especial interest in relation to such characters as honesty, intelligence, and moral ideals; for these are among the factors that determine the real worth of men and women. If these characters are determined mainly by heredity, the quality of the men and women of the future depends upon the type of the fathers and mothers in the present generation, and the matter of proper unions in marriage is of supreme moment. On the other hand, if the characteristics of the individual are determined mainly by environment, marriage into a family, even of the lowest type, is of comparatively minor importance, so far as inheritance is concerned, and the welfare of future generations depends, not upon "good blood," but upon the type of environment that surrounds the children of the future.

Early Ideas Concerning Influence of Environment. A few generations ago it was almost universally believed, even by leading thinkers, that environmental influences practically determine the nature of the individual plant or animal. This was thought to be the case with many characters in living things, and especially with the mental traits of man, such as those concerned in immorality, dishonesty, and pauperism, on the one hand, and in the more desirable human traits or conditions on the other. If the boy got into bad company and became a criminal, a large portion of the blame was attributed to the influence of poor environment. On the other hand, if a boy succeeded and developed into a man of high character and ideals, it was thought to be the result, very largely, of good environment.

Effect of Plant and Animal Breeding upon This View. The breeding of high class domestic animals and cultivated plants taught breeders that this extreme view was incorrect, and that, in order to achieve good results, the hereditary natures of the animals and plants had to be considered. At present, everyone acquainted with the principles involved in the improvement of animals and plants knows full well that "*blood counts*," and that no type of environment, no matter how good, can make up for the absence of high class hereditary traits.

No man of any practical experience whatever would consider the possibility of producing a high class hog, a fine horse, or a prize winning bird-dog from offspring of inferior parents. Good blood is absolutely essential if results of this sort are to be attained. All breeders know that good environmental conditions are important, but these alone are entirely insufficient. This is why stockmen often pay extreme prices for high class animals for breeding purposes.

A Widespread Belief as to the Effect of Environment upon Human Beings. The facts just mentioned are so well recognized everywhere that it would be unnecessary to state them, were it not for the fact that they are often lost sight of when the children of human parents are involved. Many people appear to think that the child does not obey the laws that apply to all the

lower animals and plants; but this is far from the truth. All scientific evidence indicates that *the developing child behaves in exactly the same way toward hereditary and environmental influences, in general, as do the lower animals.*

The facts obtained from the breeding of animals should be definitely applied to human beings. If good environment cannot make up for poor heredity in the horse, neither can it overcome a deficiency in the inheritance in a human being. *It is true that environment plays an important part in the development of the child, but it is not true that these influences are all-important, as is sometimes held to be the case. Heredity exerts an influence that must be recognized if the next generation is to be what it should be.*

More Recent Views Regarding the Influence of Heredity. During the closing years of the last century and the first decade of the twentieth century, a great change in the views regarding the importance of heredity took place. As a result of certain investigations upon the inheritance of intelligence and of height of men, and upon similarities between twins, the importance of heredity in influencing the development of the child was greatly emphasized. Discoveries also were brought to the attention of scientists that indicated clearly that hereditary influences determine various qualities of garden peas. It was shown that characters may disappear from sight, or be covered up, as it were, in one generation, to reappear in the subsequent offspring in definite numerical ratios. In other words, it was apparent that inheritable characters or traits, in certain cases at least, behave according to fixed laws. (Page 331.)

Very soon, many characters of plants and animals were found to be transmitted in accordance with these new ideas. In man, also, definite family traits, such as eye color, various physical deformities, and several mental characters, such as musical ability, superior intellectual capacity, and feeble-mindedness, seemed to follow these newly discovered laws of heredity.

Extreme View as to the Influence of Heredity. As a result of these remarkable discoveries and observations, the influence of heredity upon the development and character of man received such emphasis that the effect of environment was looked upon, by some

at least, as of comparatively minor importance. One great authority stated that in a large number of human characters that were studied with care, hereditary influence "prevails enormously" over environment, when the variations in the surroundings of the individuals under consideration are not greater than those affecting people of the same general social class in the community.

There is no question that the influence of heredity is powerful in determining the characters of an individual; but to imply that inborn traits are virtually all-powerful, is as far from the truth as the earlier belief that environment was the chief factor to be considered.

Extreme View Not Widespread. The extreme belief as to the importance of heredity was never so widespread as the earlier idea of the importance of environment. These later ideas were confined largely to some of the scientists who were investigating the problem, and consequently, did not gain much of a foothold with the general public.

As investigations were carried on with greater and greater care, the view that heredity is always predominantly important in shaping the individual lost ground, and the truth concerning the relative importance of the two sets of influences began to appear in a most convincing manner.

The Modern View as to Heredity and Environment. The prevailing belief at the present time occupies a middle ground between the two extreme views discussed above. It is now recognized that *both heredity and environment are important in the development of the individual*. As to which is the more influential, no sweeping statement can be made. In a large majority of cases, the given character is due to the effects of the inborn trait coupled with external influences. Inherited musical talent, for example, is not sufficient to produce a high class musician apart from training and effort. On the other hand, no amount of training or effort on the part of the individual can produce the accomplished artist, without the inherent qualities upon which to build.

Average Capacity Contrasted with Special Abilities. Some training in music, in science, and in business, is of value for people

of average intelligence, who constitute a large proportion of the population. But unless the individual possesses inherent qualities specially fitting him for a certain calling, a high degree of excellence in a given type of work can not be expected. Probably more mistakes in life are made through failure to consider this important principle than in any other way.

Heredity and Environment Compared. *Heredity determines the possibility of development in a given line. Environment, on the other hand, is the means through which the inborn traits, whether great or small, are developed. Training can develop only what is present; it cannot create in a person a capacity to do a certain type of work.*

Heredity Sometimes All-important. In some cases, heredity is the outstanding factor in producing differences between men. In hereditary feeble-mindedness, for example, the inborn trait rigidly determines the level of mental development that will be reached. Evidence shows that no amount of training or other known environmental influences can overcome the deficiency. To be sure, some improvement may take place, due to growth, but this is always slow when compared with that of the person of normal intelligence. The student may cite other cases of this general type.

Environment at Times Very Influential. There are cases where environment seems largely responsible for the differences between individuals. If two boys with essentially equal hereditary natures, were placed under widely different influences — the one in a good home, with excellent school advantages, and with high class moral influences about him; the other in a hovel, with practically no training and schooling, and with degenerate people as associates — the ultimate differences between the two individuals would be largely the result of environment. Even in this extreme case, however, heredity would play some part, for in a group of boys or girls under the same type of environment the individuals vary in the degree that the influences affect them. This variation must be attributed, in general, to heredity.

LAWS OF HEREDITY

Gregor Mendel. More than a half-century ago Gregor Mendel, an Austrian monk, discovered the principles upon which the modern science of heredity is based. His discoveries, now looked upon as some of the most important of all time in the field of biology,

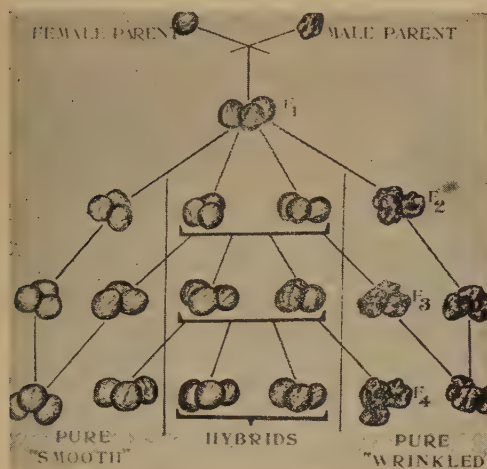


FIG. 156. — THE RESULT OF CROSSING A SMOOTH WITH A WRINKLED PEA

F_1 , F_2 , F_3 , and F_4 represent successive hybrid generations. (From a wall chart by the author)

attracted so little attention when published in 1866, that the work was soon forgotten. In 1900, three scientists who were working independently upon heredity, re-discovered the principles formulated by Mendel a generation earlier, and re-published his results. This date marks the beginning of the modern intensive study of heredity. Scientists in all parts of the civilized world verified Mendel's work, and very soon it became

apparent that the discoveries of this obscure Austrian monk would revolutionize ideas concerning the influence of heredity and environment upon the development of plants and animals.

Mendel's Experiments. Mendel worked with pure varieties of garden peas that differed from each other in certain easily observed characters, including smooth or wrinkled seed coats, tall or short stems, smooth or wrinkled pods, green or yellow seeds, and some others of the same general nature. These contrasting types were crossed with each other and the offspring were carefully studied through several generations.

Experiment with Wrinkled-coated and Smooth-coated Peas. The crosses between the peas with smooth seed coats and those with wrinkled seed coats will make clear the nature of the experiments. As a preliminary, but very important step, these two types were shown to be pure, relative to these characters; that is, the one always developed smooth coats and the other, wrinkled coats. The two pure types were then crossed in the usual way, through the transfer of pollen from the one to the stigmas of the other, with precautions to prevent the entrance of other pollen.

The Hybrid Seeds. When seeds developed from the flowers pollinated in this way, it was found that *all of the seeds were smooth*. This is surprising; for the wrinkled coats present in one of the parents did not appear at all in the seeds of this first hybrid generation. The seeds were not intermediate between the two types, as might be supposed; they were apparently just as smooth as those of the pure smooth-coated parent. What had happened to the character, and whether it had permanently disappeared from the plants, were questions of great interest to Mendel.

Results of Crossing the Hybrids. These questions were definitely answered through further experiments and observations upon the smooth-coated hybrid seeds. Mendel planted these and carefully self-pollinated the flowers that developed. When the seeds ripened, a very remarkable fact appeared: approximately, *one-fourth of the total number obtained were just as wrinkled as the original pure wrinkled parent*. Evidently, something that determined the wrinkled character was present in the plants that produced the smooth round peas of the first hybrid generation, but had been covered or held in check, so to speak, during development.

Certainly, it was significant that perfectly smooth peas could give rise to wrinkled offspring, but it was even more so, that in every case where large numbers were used, approximately one-fourth of the seeds of the second hybrid generation were wrinkled. Moreover, the wrinkled peas of this generation bred true, giving rise to seeds of this type only. In other words, *they were pure, relative to this character* — just as pure as the original type used in the first cross.

Smooth Round Peas of the Second Hybrid Generation. The

remaining three-fourths of the seeds of the second hybrid generation were all round and apparently just alike. However, when planted and self-pollinated, approximately one-third of these, or one-fourth of the entire total, proved to be pure with reference to the character of smoothness; that is, they produced only smooth-coated peas, identical in every respect to those of the original smooth-coated parent. The other two-thirds of the round peas, amounting to two-fourths, or one-half, of the total second hybrid generation, when planted and self-pollinated, produced peas of the same types and in the same ratio as those of the first hybrid generation: one-fourth pure wrinkled, two-fourths hybrid round, and one-fourth pure round. (Fig. 156.)

Mendel's Conclusions. Mendel's results indicated three important facts concerning the behavior of inheritable characters in garden peas. 1. Characters are transmitted from parents to offspring as independent units; or in other words, they are *unit characters*. 2. When two contrasting characters, such as wrinkled and smooth seeds in peas, are present in a hybrid, the one, known as the *dominant*, appears to the exclusion of the other, called the *recessive*. 3. When contrasting characters are brought together in a hybrid, *these characters appear in definite numerical ratios in the second hybrid generation*.

Early Ideas of Unit Characters. Former views with regard to unit characters are well illustrated in Mendel's crosses between peas with smooth coats and those with wrinkled coats, described above. The wrinkled coats of the one parent disappeared in the first hybrid generation, but reappeared unchanged in one-fourth of the peas of the second hybrid generation. Apparently, this character was not modified or broken up by the influence of the smooth-seeded parent. The structure or substance in the germ cells, whatever it may be, that caused the development of the wrinkled coats, apparently remained unchanged in the smooth-coated peas of the first hybrid generation. In other words, the *determiner* of the character, which represented it in the germ cell, behaved as a *unit*, or maintained its individuality, and consequently was able to produce the pure wrinkled peas of the second hybrid generation.

Present Ideas of Unit Characters. In subsequent experiments it was definitely observed that many hereditary characters in plants and animals are transmitted from parent to offspring, generation after generation, largely retaining their individuality. In other words, they *behave much as if they were units*. In man, for example, we find all sorts of traits, both mental and physical, such as musical ability, feeble-mindedness, and eye color, which run through families for many generations. These characters are sometimes modified by various causes, but they generally maintain their individuality.

As evidence accumulated with reference to inheritance in plants and animals, the early views of unit characters were modified. The old idea that a character is represented in the germ plasm by a *single determiner* is no longer held. It is now believed that a *given character* is often influenced by a *number of determiners* and, on the other hand, that a *single determiner* often affects a *number of different characters*.

Source of the Characters of an Individual. An individual, from the standpoint of heredity, is looked upon as a sort of human mosaic, (Fig. 164) made up of a large number of independent inheritable characters, both mental and physical. These have been passed down through the ancestors, and make up the hereditary nature of the person. In each individual, some of the characters have been lost and others have been retained; but which, of all the ancestral traits, are retained, is fundamentally a matter of chance.

In a family of superior blood, the individual is much more likely to possess a fine assortment of characters than in a family of low or degenerate stock. With each child, there occurs a sort of reshuffling of the multitude of ancestral traits, with the result that each individual is practically certain to possess a different assortment. This explains the differences often observed between the children of a family.

Early Ideas of Dominance. The crossing of pure, smooth-coated peas with pure, wrinkled-coated peas, produces offspring which are all as smooth as the smooth parent. It is evident that in

the peas of this first hybrid generation, the determiner for wrinkledness is present; for, when these are planted, this character reappears in a fourth of the peas of the second hybrid generation. When the determiner for smoothness is present, it seems that the one for wrinkledness is prevented, in some way, from exerting its influence, and wrinkled coats are kept from developing. The other pairs of characters in the peas with which Mendel worked, behaved much in the same way. Consequently, it was concluded that, where two contrasting characters enter into a cross, one dominates the other and prevents its development. Therefore, the one was referred to as *dominant* and the other as *recessive*.

Present Ideas of Dominance. The ideas of dominance as given above have been much modified during recent years. In some cases, it *appears* that one character completely dominates the other, but this is now seriously questioned. In other cases, the dominance is said to be *incomplete*. For example, when a certain strain of black chicken is crossed with a certain white type, the offspring are neither black or white, but of a bluish-gray color. In other crosses, dominance is *delayed*, and the character changes gradually during development, as is seen in the change in eye-color in some babies from bright blue to brown, during the early years of childhood. On the whole, however, the terms "dominant" and "recessive," are of value in indicating the apparent behavior of characters in hybrids.

Dominant and Recessive Characters in Man. In human beings, as well as in lower animals and plants, the fact that a character can pass through a generation as a recessive and, consequently, be hidden, is of the highest importance. If the character behaves as a dominant it is easily recognized when it is present in the individual, but if the character is a recessive, the matter is much more complicated, and the facts are often very difficult to obtain. Especially is this true in man. Take, for example, feeble-mindedness, which is certainly hereditary and is definitely recessive to normality. This undesirable trait may be present in an individual who is apparently normal, cultured, and refined, and, to all appearances, of good heritage; yet, if this individual marries another

who carries the recessive trait of low mentality, approximately one out of four of the children of this family will be feeble-minded.

Recognition of Dominant and Recessive Characters. If a dominant character is present in the individual plant or animal,



FIG. 157.—A PURE BLACK SHORT-HAIRED GUINEA-PIG CROSSED WITH A PURE WHITE LONG-HAIRED GUINEA-PIG
"Black" and "long hair" are dominant.

(From Babcock and Clausen, *Genetics in Relation to Agriculture*, McGraw-Hill Book Company, Inc., New York. By permission)

generally expressed, the $1:2:1$ ratio, is Mendel's fundamental discovery, and is now known as Mendel's law. This ratio and others that appear when more than one pair of contrasting characters are used in the crosses, together with the underlying causes of these numerical relationships, form the working basis for the science of Mendelian heredity. No results have been obtained that differ from Mendel's, and no changes have been made in his explanation as to the cause of the ratios, other than a broadening and an exten-

it will appear; but a recessive character may or may not appear, depending upon conditions. Often the facts may be obtained only through the study of blood relatives of the individual concerned. If a recessive trait does not appear in the blood relatives of the immediate generation, or in the near ancestors, the character is probably not present in the family blood. This test is of great importance in the human race.

Mendel's Law. The appearance, in the second hybrid generation of peas, of one-fourth pure round, two-fourths hybrid round, and one-fourth pure wrinkled seeds, or, as it is

sion necessary to include new cases that have arisen from experimentation during the last quarter of a century.

Segregation of the Determiners of Characters. The explanation as to why the ratio, 1:2:1, appears in hybrids, is comparatively simple. Take again, for example, the cross between smooth-coated and wrinkled peas. The plants of the first hybrid generation contain the determiners for both of these characters, but when the sex cells are formed in these plants, whether eggs or sperms, the pairs of determiners representing these characters are *separated or segregated*, one member of the pair passing to one sex cell and the other going to another sex cell. That is, there are two kinds of egg cells and two kinds of sperm cells formed, and there are just as many egg cells carrying the determiner for smoothness as there are containing the determiner for wrinkledness. The same is true of the sperm cells. Each germ cell is said to be *pure*, relative to a given character; that is, it carries one and only one of a pair of determiners influencing a given character.

Combination of Germ Cells in Fertilization. When fertilization occurs, a single sperm cell unites with an egg cell. There are four combinations possible, and since it is a matter of chance which kinds of cells function, one combination is just as likely to occur as another. The diagram below will show why this is true.

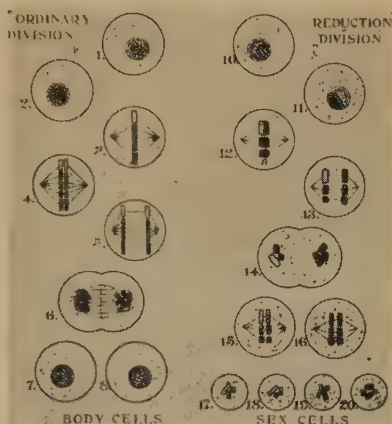
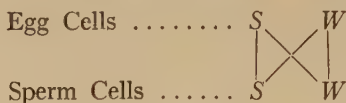


FIG. 158. — BEHAVIOR OF CHROMOSOMES IN ORDINARY (Mitotic) AND REDUCTION DIVISION (Diagrammatic)

Note that in ordinary division the chromosomes arrange themselves end to end (3), while in reduction division they appear in pairs (12). In reduction division the pairs become separated (13), and thus the resulting sex cells contain one half of the number found in the body cells (14, 15, 16). The pairs of chromosomes may be arranged in a number of other ways than that shown in 12. (From a wall chart by the author)

S represents the determiner for smoothness, and *W*, the determiner for wrinkledness. In the unions of egg cells and sperms in fertiliza-



tion, *S* may combine with *S*, giving one pure smooth type, *S* may combine with *W*, or *W* may combine with *S*, giving two hybrids of the *SW* type, or *W* may combine with *W*; giving one pure wrinkled type. This is the ratio, 1:2:1, that occurs in the second hybrid generation, when two plants, differing in one character, are crossed.

New Combinations of Characters.

When plants or animals, differing in two or more characters, are crossed, ratios derived from the 1:2:1 ratio result, and new combinations of characters are found in the hybrids. These new combinations form the basis for new varieties of plants and animals. For example, if a yellow smooth-coated pea is crossed with a green-wrinkled type, there will be four kinds of peas produced in the second hybrid generation; namely, yellow-smooth, yellow-wrinkled, green-smooth, and green-wrinkled peas. Here we find two new combinations, the yellow-wrinkled, and the green-smooth types. If one or both of these varieties are desirable forms for the garden, they may be isolated and made to breed true.

Sometimes varieties derived in this way are permanent from the first, but with others a careful and long-continued selection is necessary to make and keep

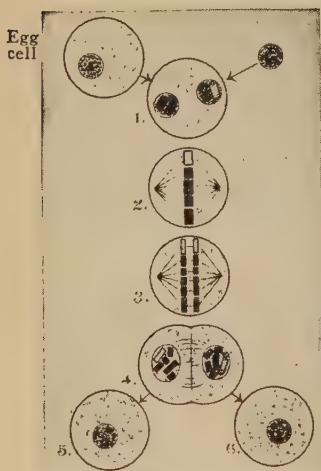


FIG. 159. — BEHAVIOR OF CHROMOSOMES IN FERTILIZATION (Diagrammatic)

Note that the fertilized egg (2) contains double the number of chromosomes found in the sex cells, and that each sex cell furnishes half. Also that in the succeeding divisions (3, 4, 5, 6), each new cell receives half of its chromosomes from the male and half from the female parent.

(From a wall chart by the author)

them true to type. If the plants or animals crossed differ in a number of distinct characters, the numerous possible combinations greatly complicate the matter of fixing the variety. Sometimes breeders find it impossible to do so.

Chromosomes and Hereditary Transmission. During recent years, evidence has accumulated that indicates with almost absolute certainty that the chromosomes are instrumental in the transmission of hereditary characters. The behavior of the chromosomes during ordinary cell division, reduction division, and fertilization is very significant. (Page 97.) These complex processes provide the marvelous mechanism necessary for hereditary transmission. The exceedingly complicated results obtained in breeding experiments often find their explanation in the behavior of the chromosomes. Recently, scientists were able to locate with accuracy the relative positions of the determiners for many characters in the chromosomes of certain flies.

Cytoplasm of the Egg Cell Also Important in Heredity. It should be pointed out that, although the chromosomes are fundamentally concerned in the transmission of hereditary traits, the cytoplasm of the egg cell is also of importance. The distinctive characters of a certain chicken, for example, such as color, nature of feathers, comb structure, and egg-laying capacity, seem to be determined through the chromosomes; but those basic features that make the chicken a vertebrate rather than an invertebrate, and a bird rather than a fish, are determined through the cytoplasm of the egg cell. In other words, the chicken is a chicken because of the cytoplasm of the egg cell, but whether it is black or white, has a rose or single comb, or has superior or inferior egg-laying capacity, depends upon the determiners within the chromosomes of the sex cells that produce it.

CASES INVOLVING HEREDITY

CULTIVATED PLANTS

Shasta Daisy. The story of the origin of the Shasta daisy, one of the most valued of our garden plants, illustrates just what is

meant by new combinations of characters and how such results may be obtained. This plant was built up, so to speak, by Luther Burbank, by bringing together through crossing certain inheritable characters found in three distinct types of daisies: a very hardy plant from New England, a lustrous white one from Japan, and a large-sized type from England. Besides these three outstanding characters, there were, of course, a large number of other differences present. By combining the various desirable characters of these three plants and weeding out the undesirable ones, Mr. Burbank was enabled to produce the Shasta daisy.

Crossing the Daisies. The three types of daisies were crossed with each other. Finally, in the hybrids resulting from these crosses, the characters of the original plants became thoroughly broken up or separated. These complex hybrids were then multiplied until there were many thousands of plants, which were set out in a field and allowed to develop. In this field of hybrid daisies all manner of combinations of characters appeared, uniting traits of the most diverse nature and thereby producing many remarkable plants. This was to be expected, for it should be kept in mind that besides the three outstanding characters — namely, the *hardiness*, the *whiteness* of the flowers, and the *large size* — there were a myriad of others present in the original plants, and these, whether desirable or undesirable, had equal chances of appearing in the hybrids.

Necessity of Producing Many Plants. Where many different characters are involved in crosses, it is only by the remotest chance that the right combination may be obtained without including characters interfering with the desired result. For this reason, it is necessary, in work of this kind, to use vast numbers of individuals; otherwise there is little chance of success. In the case at hand, it is said that Mr. Burbank finally obtained, through multiplication of the original crosses, a hundred thousand of the hybrid plants, representing almost innumerable combinations of characters. Consequently, selecting the most promising individuals from all the multitude was a task requiring great skill and sound judgment.

Selection of Promising Plants. The vast number of hybrid daisies were set out in a fertile field and allowed to develop. Time

and again, as the flowers opened, the field was searched for types that approached the ideal held in Burbank's mind — a graceful and prolific snow white daisy of great size and hardiness. A comparatively small number of the most promising plants were allowed to produce seed, which in turn were planted, and the search for still better types proceeded. This was continued for eight years, it is said, until finally the Shasta daisy as we see it to-day resulted.

Plants Grown from Seeds Difficult to Purify. If the plant containing new combinations of characters is to be propagated from seeds, the problem of purifying the hybrids is much more difficult than if vegetative methods, such as budding, grafting, or some other way of dividing the parent plant, are resorted to. This is due to the fact that recessive characters may not appear in a certain hybrid plant, but still show up in the offspring, as in the case of wrinkled coats of peas. To eliminate undesirable traits that behave in this way is sometimes a tedious and difficult, or even impossible, task. Selection through several generations, however, often accomplishes the end.

Selection Purifies Hybrids. In applying selection to a large number of plants, all of those showing undesirable characters are culled out and destroyed, and only those of the desired type are left to produce seeds. In this way, many of the poor traits that appear in the plants are excluded and many of the good characters are retained. This process, continued for several generations, generally brings about great improvement in the type. With many of our garden plants, selection must be continued from year to year, in order to keep the varieties up to standard; with others, as for example, some of our self-pollinated grains, the seeds appear to come true to type from the first and to maintain their original purity without selection. (Read section on good seeds, page 51.)

Permanent Character of Grafted Plants. Plants propagated by budding or grafting do not offer the difficulties relative to the inheritance of undesirable characters encountered in those grown from seed; for with the former there is no chance for new combinations of characters to appear in the new plants. Whatever method is used in vegetative propagation, the old plant is divided up, and

the parts or buds which give rise to the new plants carry the same combination of inheritable characters possessed by the parent. Our fine orchard fruits develop qualities that make them desirable; but in the germ plasm, or inheritable substance, of these same plants, recessive traits are hidden, and appear at once when seeds are allowed to develop. This is why the seeds from the Alberta peach, for example, do not produce trees of this variety, but on the contrary, seedlings in which almost any combination of the characters of the peach may appear.

Origin of Our Cultivated Fruits and Berries. Many of our fruits and berries have been derived from accidental seedlings, often found in a wild state by someone who, recognizing their valuable qualities, has brought them under cultivation, and propagated them by cuttings or buds. In such cases, cultivation has fostered the development of the hereditary qualities present; but on the other hand, it has in no way changed the true nature of the plants.

DEVELOPMENT OF THE MODERN HORSE

Origin of the Horse. That horse-like animals have been upon earth for millions of years is indicated by remains occurring in stratified rock that is known to have been formed in very remote periods. A complete series of fossils of these animals has been collected, and it shows step by step that the horse of to-day has evolved from a much smaller and very different type, that existed possibly two million or more years ago. This earliest known ancestor of the horse was about the size of a fox, with four hoofed toes and rudiments of a fifth on the front feet, and three hoofed toes on the hind feet. So different is it from the modern horse that it could scarcely be recognized as a relative were it not for the complete series of intermediate forms between it and the modern animal.

Change in the Horse in Geological Times. As the long periods of geological time passed, types of animals related to this early form appeared and, in successive periods, became larger and larger, and more and more horse-like. Finally, in quite recent times, but long before the period of recorded history, wild horses, very

similar in structure to those we see about us, roamed over the continents.

It is interesting to note that during this long development the various structures found in the modern horse gradually came into existence step by step. In the development of the foot, for example, the toes disappeared in the successive forms, one by one, until only one remained. During this reduction in number, this

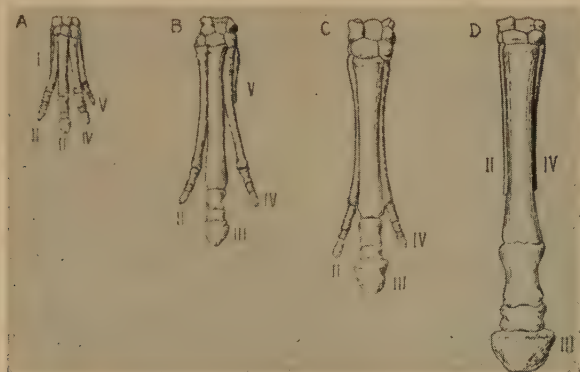


FIG. 160. — CHANGES IN THE FRONT FOOT OF THE HORSE DURING GEOLOGICAL TIMES

The Roman numerals indicate the corresponding digits (toes) in A, B, C, and D. (From *General Biology* by Burlingame, Heath, Martin, and Pierce, Henry Holt and Company. By permission)

one toe increased in size, and the characters of the modern horse's foot gradually came into existence. The other toes became smaller and smaller, and some of them finally disappeared, while others persisted as splints, which are to be found to-day upon the horse's foot.

Domestication of the Horse. The horse, practically as we find it to-day, lived in the wilds for ages. During all this time, hereditary characters were preserved that enabled it to survive in the severe struggles of the wilderness; otherwise, it could not have continued to exist. In this condition, with many excellent qualities, as well as with numerous undesirable traits from the standpoint of

man's needs, the wild horse was domesticated. Man has been eminently successful in building up the various specialized types of horses from this wild mongrel stock, and the results illustrate well what can be accomplished through intelligent selection in the breeding of animals.

Use of the Horse. The horse was domesticated in about the eighteenth century, B. C. Records dating this far back show that the animal was first used to draw the war chariots of ancient peoples and to carry on their backs the troops of cavalry. In later times, the horse came into general use for agricultural purposes, and more recently, it has been developed for the chase, for racing and for road purposes, as well as for numerous other needs.

Need for Different Types of Horses. When man adopted the horse for definite purposes, selection seems to have been employed, almost from the first, in order to procure types best fitted for the use at hand. The powerful and fiery war-horse, suitable for use in the cavalry and for other army purposes of earlier days, was a very different type from the gentle and steady animals adapted for agricultural pursuits. Again, the types used to-day for hunting, racing, and general road purposes, differ greatly from the heavier and slower draft-animals.

These widely different uses for which the horse was employed determined the course of the selection in the development of each breed. The early wild type with its multitude of characters furnished excellent material upon which to work, and from these animals man was able to select the varied combinations of hereditary traits that form the basis of the different breeds of horses of the present day. Just how this was accomplished is well illustrated by the development of the horses of England during the last few centuries.

The Horse in England. Little seems to be known concerning the early native horses of England, but it is said that these were crossed with the cavalry animals from the south, at the time of the Norman conquest. Later, heavy types from Flanders, and light swift animals from Spain, Persia, and other countries, were introduced for breeding purposes. In the time of King John, horses

were brought in for the express purpose of improving the types used in agriculture. During more recent times, many fine Arabian and Turkish horses were imported to improve the racing and hunting types that were, and still are, so popular in England.

The Thoroughbred Racer. As a result of this influx of blood from the fleet and active, as well as beautiful horses of the Orient, the characters necessary for the development of the modern thoroughbred racers were acquired. It is said that the pedigree of practically every record-breaking thoroughbred may be traced back through a century or two, to one or another of a small number of these famous horses brought to England from the East.

The Production of a Breed of Horses. In a general way, a breed of horses is produced as follows: a number of the most promising animals for a given purpose are chosen from a large group where careful selection has been practiced for some time. These animals, possessing many desirable characters as well as some not wanted in the breed, are crossed with each other within the selected group. In this way, undesirable traits from the outside are excluded, and good hereditary characters of one animal are combined with those of another in the group. The offspring from these crosses are again selected with great care, and only the most promising are used for breeding purposes. This process, continued for several generations, may result in a type characterized by definite combinations of hereditary traits that breed true.

Thoroughbreds. The ideal held by the breeders in the development of the thoroughbreds, or racers, of England included speed, intelligence, endurance, courage, and, as an accompaniment of these, beauty of form. In the original group, chosen from the best native stock and augmented by the fine importations from Arabia and other eastern countries, possibly one animal possessed great speed but lacked intelligence; another had intelligence and great endurance; and others had excellent body form and desirable gait, or other characters equally valuable in the great racer. The superior race-horse must possess many of the traits that were at first scattered throughout the group.

The problem, then, of the animal breeders in the development of

the racing type, was to eliminate the detrimental qualities and to combine in one type the desirable traits, by careful selection and proper crossing. How thoroughly this has been accomplished during the last two centuries is indicated by the words of an authority upon the horse — "It can be truthfully said that the blood horse (thoroughbred) has almost reached the highest state of possible improvement, and is the most perfect of the horse kind. For beauty, intelligence, courage, speed, and endurance, nothing approaches him."¹

HEREDITY IN HUMAN FAMILIES

Hereditary Traits in Man as Compared with Those of Plants and Animals. Hereditary traits are just as definitely determined in the human species and behave in essentially the same way as in the Shasta daisy, the race-horse, or other types of plants and animals. But with the domesticated plants and animals, the breeders have used careful selection in order to retain the good characters and to weed out the bad, whereas with man this procedure is obviously impossible. It should be said, however, that there is a strong tendency for the members of high class families to intermarry, and the same is often true relative to those of low type. But there are many exceptions, and it is extremely common for unions to occur between people differing greatly in their hereditary traits, both physical and mental.

Wide Variation among Human Beings. The human race is composed of types very far from pure in the sense used in reference to high class animals and plants. In a brood of pure bred chickens, for example, each fowl is essentially similar to others of the group, but in a family of children, all sorts of combinations of characters may occur. This is frequently striking when the parents are very different in disposition, in intelligence, and in various other mental as well as physical traits. One child may resemble the mother, one the father, and others may combine definite traits from both the parents.

¹ From *The Horse* by Roberts, published by permission of The Macmillan Company, New York, Publishers.

The Importance of Heredity in Man. Since individuals and families differ so widely in their hereditary natures, and since certain traits, such as feeble-mindedness, may be carried by an indi-

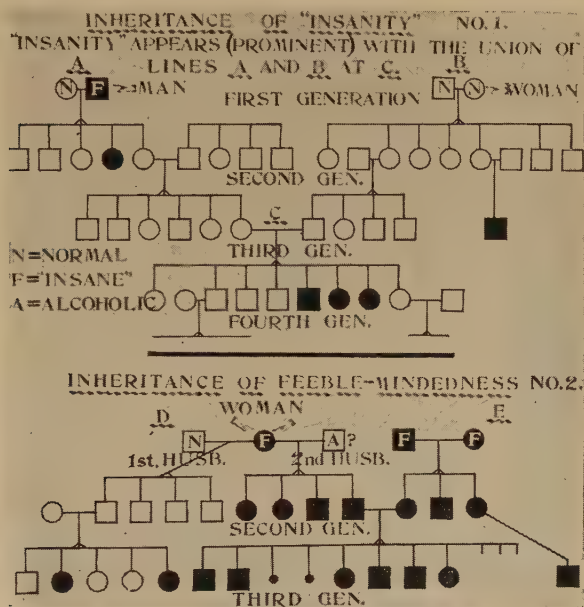


FIG. 161. — MARRIAGE AND MENTAL DEFECTS

Above (1) — Chart showing the result of marriage between two apparently normal people from families where defects are present. At C the woman, represented by the circle, has an aunt and grandfather who are deficient. (Black indicates mental deficiency.) The man at C has a deficient cousin. Out of eight children from this marriage, three are mentally defective.

Below (2) — This chart indicates the result of the marriage of two feeble-minded people. (Black square and black circle at the right of the center in the second generation.) From this union eight children were born; two of them died in infancy (small circles) and six are feeble-minded.

(No. 1. Copied from Davenport (after Mott), *Heredity in Relation to Eugenics*, Henry Holt and Co. By permission. No. 2. Copied from Goddard, *Feeble-mindedness, Its Causes and Consequences*, The Macmillan Company. By permission)

vidual who, himself, is normal, it is important for every thinking young person to understand something of the way inheritable traits run in families. The young person of to-day cannot afford to neglect this subject; for it is concerned with some of the most important matters of life — the *homes and the children of the future*.

Selection Used in Ancient Times. *Sparta.* One outstanding example where selection was used in a group of people for a definite purpose, is found in Sparta during the period from the eighth to the fifth centuries, B. C. The results obtained in those days are similar to those achieved by modern man in the development of our various types of domestic animals for special uses. The ideals held by the ruling group of Sparta, relative to good citizenship and value to the State, were based upon prowess in war, and included such traits as physical strength, courage, vigor, endurance, and ability to stand pain. In other words, the ancient soldier, invincible and unconquerable, was the goal.

With this end in view, it is said that all male children were brought before the ruling council and judged as to their fitness. Those that were puny, diseased, or crippled, and thus not qualified for this service to the state, were exposed on the mountains to perish. Only the strong and vigorous were allowed to live. This group, as property of the State, was then trained from an early age for the business of war. As a consequence of this selection and training, soldiers were produced who have been famous through all time for their prowess.

Athens. Another example of human selection, unconscious but effective, took place in ancient Athens during the time of its intellectual supremacy. Here a high estimate was placed upon achievement in art and in poetry, as well as upon physical beauty and individual prowess. People of merit from far and near settled in this city, where philosophy, culture, and refinement were so greatly valued.

Members of the intellectual classes generally married others of the same group; so the blood of the mediocre and lower families seldom mingled with that of the aristocracy. As a result of the separation of the intellectual classes from those lower in the scale, there appeared

during several centuries, beginning with 500 B. C., a race of people whose average intellectual capacity has never been equaled or even approached by any other nationality on the face of the earth. Such names as Aristotle, Plato, Socrates, Pericles, Phidias, Xenophon, Demosthenes, and many others, belong to this period.

The Decline of the Athenians. As time passed, however, morality became lax, marriages within the illustrious group were looked upon with disfavor, and as a consequence, the mothers of the incoming generations were of mediocre or low grade. As a result, the high class intellectual types of Athens degenerated and finally disappeared. When selection ceased among the ruling classes, the combinations of hereditary characters that made possible the geniuses of the period ceased to exist, and soon the population was reduced to the common level of the surrounding peoples.

In this group of human beings, exactly the same thing happened as takes place in blooded stock or in high type vegetables when selection ceases. *A high class human family can retain its excellence only so long as the marriages of its members are with individuals of the same type. Marriages with lower types can result only in a deterioration in the sum total of desirable family qualities.*

THE "JUKES"

*crime
feeble-minded*

The name "Jukes" has been applied to a group of families, forty or more, all of which have apparently descended from a few degenerate individuals who lived in the state of New York during the middle of the eighteenth century, from 1720 to 1780. The group, including the early members as well as the descendants in recent years, has become notorious because of the number of criminals, paupers, and moral degenerates that it has produced. The jails, almshouses, and insane asylums of New York have housed large numbers of these people. It is said that the members of this family have cost the state a million and a quarter dollars in the criminal courts alone. The "Jukes" furnish a striking illustration of the inheritance of undesirable qualities in man, and of the effect of a single, or a few degenerate ancestors, upon future generations.

History of the "Jukes." The facts concerning this family, as worked out in 1874-77, are about as follows. The father, known as "Old Max," was born of Dutch parents in about 1720. He is said to have been an indolent, trifling sot, who cared nothing for education, but loved to fish, hunt, and tell vulgar stories to anyone who would listen to him. He was looked upon by his associates as a "jolly good fellow." He lived in the back woods, where he built a hut. He married a woman probably of his own type of character, and had many children. Two of the sons married sisters from a family of six girls, whose ancestry is uncertain, but whose hereditary traits were without doubt of the lowest type. From this group, including the two sons of Max and the six girls, who are all referred to as "Jukes," there came a large number of children who resembled the parents in their immoral, lazy, criminal, and otherwise undesirable tendencies. These children married members of their own family or of other low type families, and the same sort of marriages occurred in succeeding generations, down to the time when this history was worked out.

Mr. Dugdale, who carried on this investigation, states, "The number of descendants registered (studied) includes 540 individuals who are related by blood to the Jukes, and 169 by marriage or cohabitation; in all 709 persons of all ages, alive and dead."¹ Besides these, he gathered considerable data concerning others, thus raising the total lineage of which he had knowledge to about 1200.

Characteristics of the Group. The traits of "Old Max" and of the family of women into which the two sons married, are scattered throughout the entire "Jukes" group. Among them are *indolence* and *shiftlessness*. It is said that less than two dozen "Jukes" ever learned a trade and that half of these did so under compulsion while in prison. Moreover, few if any are known to have worked at an honorable calling persistently enough to make what could be properly called a living.

Indolence often leads directly to disgraceful *pauperism* or to

¹ From *The Jukes*, by Dugdale. Courtesy of G. P. Putnam's Sons, Publishers, New York and London.

crime, both of which serve as a means of obtaining the necessities of life. The data show that more than one-fourth of the group were professional paupers, depending upon almshouses or other charitable agencies. Moreover, criminals are found throughout the entire family. There were seven known murderers, a large number of professional thieves, and many who served time in the jails for various other crimes.

The prevailing *vulgarity* in the group and the general *ignorance* and *indolence*, appear to be factors involved in the excessive amount of sexual immorality found in the family. There are numerous professionally immoral women of the lowest types, and evidence indicates that hundreds of others, both men and women, are little if any better. In fact, the brief summaries of the characteristics of the "Jukes," as given by Mr. Dugdale, soon become monotonous repetitions of all sorts of immoral offenses.

The "Jukes" in 1915. A survey of the "Jukes" as they were in 1915, brings out some significant facts. In about 1875, when the earlier study was made, the family began to migrate from the ancestral home and became rather widely scattered. As a result, many of the descendants moved into much better environments, and some married into families of higher type. Nevertheless, the original bad traits of the "Jukes" have persisted. On the whole, the slow improvement of the group, of which there is some evidence, should be attributed to marriages into better stocks, rather than to any direct influence of the improved environment. (Fig. 162.)

Heredity and the "Jukes." There can be little doubt that the degenerate traits of the "Jukes" family are hereditary. Crime, pauperism, and immorality appear so constantly throughout the group that it is impossible to escape the conclusion that "bad blood" is largely to blame. It is true that environmental conditions were generally of the lowest type, but this should be looked upon as a *result* of the bad hereditary qualities, rather than the direct *cause* of the degeneracy.

Environment of the "Jukes." Backwoods conditions, such as surrounded the early "Jukes," are not to be considered as detrimental to the development of strong character; for where "good



FIG. 162. — "JUKE" HOMES IN 1915

Above, left — "Juke" family. *Above, right* — Another view of the same woman. In one side of the house lives the woman, in the other pigs are kept. *Below* — Another home. This is made from boards taken from wrecked freight cars.

(Photographs furnished by Arthur H. Estabrook who made, in 1915, the investigations upon the "Jukes" cited in the discussion.)

blood " is present, such environment is productive of high types of citizens. In fact, the simple life of the pioneers was doubtless one of the strongest factors in developing self-reliant, vigorous manhood, and even the genius of such men as Lincoln, Garfield, Clay, and numerous others.

The truly bad environment of the " Jukes " was not to be found then in the frontier conditions surrounding the earlier members of the family, but rather in the huts and hovels, unworthy to be called homes, where the children grew up under the influence of vulgar, immoral, indolent, and often criminal parents and associates. Doubtless such conditions had definite evil effects upon the children, but the real root of the trouble is to be found in the *inherited degenerate natures of the " Jukes," which made possible such an environment*. Let us keep in mind that environment does not create; it merely serves to develop what is already present. Such a history as that of the " Jukes " emphasizes strongly the important fact that, in numerous cases, heredity largely determines the type of influences to be found in the home.

THE EDWARDS FAMILY

In most striking contrast to the " Jukes," the Edwards family stands out as a notable example of the inheritance of human traits of high type. It should be said that even in this family there is evidence of characteristics that led to immoral acts in a few of the group. However, the preponderance of superior individuals, both intellectually and morally, is so great, that the evil traits seem to have been lost in a large percentage of the blood relatives.

History of the Edwards Family. The historical facts regarding the Edwards family are extremely interesting. The ancestors on the father's side have been traced back to 1282. From this time down to early colonial days, the family was of high standing in England. William Edwards migrated to Hartford, Connecticut, where his son Richard was born in 1647. This boy became a lawyer of note in the colony, and in 1667 he married Elizabeth Tuttle, a woman of great intellectual power and personal beauty, in whose

veins flowed some royal blood. One son was born to this couple, Timothy Edwards, who grew to be a man of great mental ability and became a leading pastor of early New England. He in turn had eleven children, ten daughters and one son, Jonathan Edwards, America's greatest intellect of colonial times. It may be said that this frontier preacher, with his writings and powerful logic, attracted the attention of aristocratic and intellectual Europe more than any other early American, with the possible exception of Benjamin Franklin. All authorities agree that Jonathan Edwards was an intellectual giant.

The Immediate Descendants of Jonathan Edwards. Jonathan Edwards had eleven children every one of whom is said to have inherited the traits of the father. There were seventy-five grandchildren, who were practically all of high moral standard and of great intellectual vigor. During succeeding generations the descendants of this great family have retained the ancestral characters of the early members and have always proved a positive force for good. Taken as a whole, the family is most remarkable for the number and quality of the intellectual and moral leaders it has produced.

In the direct line of descent are to be found numerous college presidents and teachers of renown, great divines and moral leaders, brilliant lawyers and judges, governors and diplomats, financial leaders and noted authors, patriots, and reformers. The extensive lists of distinguished men and women among the descendants of Jonathan Edwards are an impressive indication of the hereditary nature of the qualities that make for human greatness.

Descendants of Elizabeth Tuttle. Soon after the birth of Timothy Edwards, the father, Richard, was divorced from his wife, Elizabeth Tuttle, on the ground of her immorality. The weak strain in the blood of this woman appears, not only in her own immediate family, but also in a few of her descendants, who were licentious and immoral. However, there is evidence that many of the most admirable traits found in the Edwards family, or even a large percentage of them, according to one authority, may be attributed to Elizabeth Tuttle. After her divorce from the first

husband, she became the mother of four daughters, whose descendants possessed the same remarkable qualities as the Edwards family.

Edwards Family Contrasted with the "Jukes." The examples of the Edwards and the "Jukes" are convincing evidence that there are such conditions as "*good blood*" and "*bad blood*" in the human race, and that the idea that men are born equal is entirely false. Equality of birth from the standpoint of heredity is no nearer the truth in the human family than it is with the plants and the lower animals; and certainly no one would assume it to be the case with these forms of life.

The Edwards family is a classic illustration of the fact that "good blood" does exist and is passed on from generation to generation. Scattered throughout this group are to be found numerous leaders in all spheres of human activity, individuals whose lives have been devoted to the uplift and everlasting benefit of the human race. Their influence has affected, directly or indirectly, all regions of the country. There have been in the Edwards family but little immorality, virtually no crime, no debauchery, and no pauperism.

On the other hand, the "Jukes" stand for exactly the opposite. These people have been followers, not leaders; apparently, none of them possessed the mentality to become a leader even in crime. They followed others and committed the low, cowardly acts. Their lives have had a degrading influence upon all with whom they have come into contact. They never would have been heard of outside the localities where they lived, had it not been for the studies made by Mr. Dugdale upon the inheritance of degenerate characteristics. In striking contrast to the Edwards family, this group exhibits nothing but immorality, crime, and pauperism.

Marriages in the Edwards Family and among the "Jukes." It is a striking fact that the members of the Edwards family generally married people of superior quality. This is not surprising; for individuals with intelligence, culture, and high moral standards, usually find congenial associates in others of their type. This is why high class hereditary qualities appeared so constantly in many branches of the Edwards family.

With the "Jukes," the marriages were either with blood relatives or with members of other families of low, degenerate types; and thus the characteristic qualities of the group were retained. These examples indicate that the old adage, "One is judged by the company he keeps," is not without some scientific basis of truth.

"KALLIKAK" FAMILY

Just as the Edwards family illustrates the inheritance of intelligence and leadership, and the "Jukes" demonstrate the hereditary nature of the characteristics that lead to crime and pauperism, so the

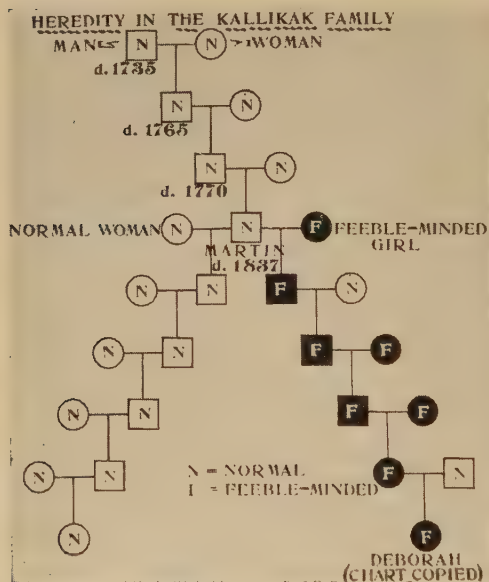


FIG. 163. — Wall Chart by the Author (Copied from Goddard, *The Kallikak Family*, Macmillan and Company. By permission)

"Kallikak" family shows how feeble-mindedness, with its concomitants, immorality and pauperism, is passed down from generation to generation. Of the eleven hundred and forty-six individuals studied in this group, which includes some families into which the direct descendants of the "Kallikak" blood married, two hundred and sixty-two were feeble-minded and less than two hundred were normal. Facts are not at hand to determine accurately the type of

the remaining members of the group. Four hundred and eighty direct descendants of Martin "Kallikak," Jr., the "father" of the family, have been studied. Of these, nearly a third were, or are,

feeble-minded, and fewer than fifty, normal. The prevalence of feeble-mindedness is most remarkable when one considers that this character behaves as a recessive. (Page 332.) (Fig. 163.)

The Origin of the "Kallikak" Family. Martin "Kallikak," Sr., was of good family, as is shown by records reaching back several generations. While a member of a company of soldiers in Revolutionary times, he lived at an inn with a feeble-minded girl. A feeble-minded child was born and the mother named him Martin "Kallikak" after the father. This boy grew to manhood and in 1803 married a woman who was apparently normal, although the character of her children indicates that she was not of good stock. There were ten children from this union, five of whom were definitely feeble-minded, and only three known to be normal. Two died in infancy, and consequently nothing is known of their mentality.

The Immediate Family of Martin "Kallikak," Jr. The history of this family is a constant repetition of feeble-mindedness, immorality, and alcoholism. The nicknames that were applied to some of the members are significant of their neighbors' attitude toward them. The father, Martin, Jr., was known as "Old Horror," one daughter was called "Old Sal," and another "Old Moll," and it may be inferred that the grandchildren were looked upon with the same disrespect.

Millard, the eldest child of Martin, Jr., who grew to maturity, married a feeble-minded girl about 1830, and the mentality of the fifteen children born to this couple illustrates what may be expected when both parents are feeble-minded. Only one out of the entire number was apparently normal; the others were definitely feeble-minded. The Mendelian laws indicate that all children of feeble-minded parents are feeble-minded; but when one considers that moral standards with people of this type are such that it is impossible to determine with certainty the parentage of the children, the exception to the rule is to be expected. (Fig. 161. (2))

A feeble-minded child of this family was Joseph, who married his cousin, also feeble-minded. To this couple were born five children, two of whom died in infancy; the others were feeble-minded. Of the

nineteen grandchildren of Joseph, there were five who died in infancy and one whose fate is unknown. *All the rest were feeble-minded.* Millard's grandchildren, through the other members of this family, though not so uniformly abnormal as these, still exhibit a large amount of feeble-mindedness, immorality, and alcoholism.

Another son of Millard was Justin, the grandfather of Deborah, who, as an inmate of the Vineland School for Feeble-minded, aroused the interest of the superintendent, Mr. Goddard, to whom we are indebted for this remarkable history. The record of this branch of the family is similar to that of the other branches, and need not be discussed; the picture is dark enough without it.

The High Class "Kallikaks." While the investigations that gave us the material cited above were being made, a remarkable set of facts came to light. In the same general region, among the degenerate "Kallikaks," was a family of the same name who differed radically from those discussed above. The members of this group had little to do with the other families, were of high character, owned their homes and were respected by everyone. This was a puzzle to the workers until certain facts were discovered which cleared up the whole matter.

When Martin "Kallikak," Sr., returned home from the Revolutionary War, he married a good woman and settled down. About five hundred descendants from this union have been traced, and among them there is practically no degeneracy of any sort. These children of Martin, Sr., generally married into good families, and all the descendants have been of superior type—property owners, and leaders in good work of all sorts. Even alcoholism in this group is seldom found, although in earlier days moderate drinking was not looked upon with much disfavor.

In the descendants of Martin "Kallikak," Sr., we have, then, the remarkable coincidence of two lines of descent emanating from one common ancestor through two different women, the one strong and of superior class, the other feeble-minded, immoral, and of inferior class. The two lines remained separate so far as intermarriage was concerned; but, on the other hand, members of the two families lived under practically the same environmental conditions, except in

so far as the grade of mentality of the groups determined the associates and immediate surroundings. It appears that the environment could scarcely have been the controlling factor in causing the differences between the two families; *heredity must have been largely responsible.*

“Kallikaks” and “Jukes” Compared. The “Kallikak” family presents more convincing evidence of the importance of hereditary influence upon degeneracy than does the “Jukes” family; for in the latter case, there is no second group of the same blood, living under a different environment, with which to compare the first. With the “Jukes,” both heredity and environment of the lowest types acted upon the whole group; while with the “Kallikaks,” the hereditary characters of the two groups within the family were different, and the environment in a number of cases at least, so far as general surroundings were concerned, was essentially similar. When two families live in the same locality, with the same school and church privileges, and mingle in a general way with the same group of people, and still remain absolutely different, as is the case with the two “Kallikak” lines, we must attribute the result largely to the influence of heredity rather than to environment.

The Influence of an Ancestor. The idea that a descendant of some great ancestor, who lived five generations or so ago, must necessarily inherit his superior qualities is far from the truth. It is possible that some of the desirable traits may be found in the

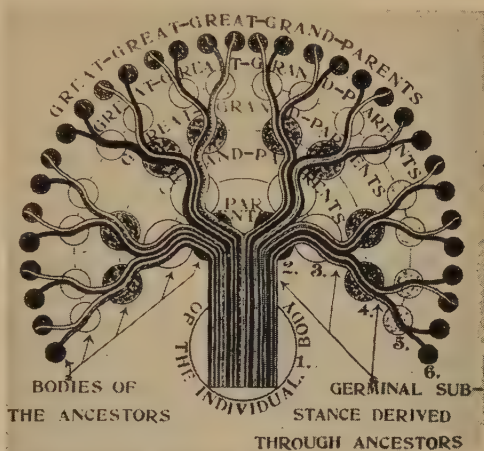


FIG. 164. — DIAGRAM SHOWING THE SOURCES OF THE INHERITABLE CHARACTERS OF AN INDIVIDUAL

(From a wall chart by the author)

present generation, if the intervening marriages have been with high class families; otherwise the probabilities are that the outstanding characteristics of the great ancestor have been lost. Five generations back, if no intermarriages of blood relatives have occurred, there are thirty-one other ancestors, each of which may have as much influence upon the present generation as the noted one. The same general condition prevails relative to the influence of a degenerate ancestor. Undesirable traits, as well as desirable ones, may, and often do, disappear from family blood. *There is but one way to maintain the superior qualities of a family, and that is through marriages into other high class strains.*

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PART IV — ANIMALS

CHAPTER XII

INVERTEBRATES

Difficulty of Distinguishing Plants from Animals. It has been pointed out that in many respects plants and animals are essentially similar. Certainly fundamental differences are not to be found in the life activities, such as digestion, respiration, excretion, and reproduction; for these processes are much the same wherever they occur, and differ in plants and animals only in minor details. Indeed, it is not an easy task to find characters distinguishing plants from animals that apply to the lower as well as the higher types. It is easy to see the difference between an elm tree, for example, and a horse; but as we descend the scale to the lower forms of life, the vegetable and animal kingdoms approach each other very closely—so closely, in fact, that biologists themselves are not agreed as to whether certain types should be classed with the animals or with the plants.

Differences between Higher Plants and Higher Animals. If we confine ourselves to the higher forms of life several differences are evident. 1. *The green plant makes its own food* out of the simple mineral substances, carbon dioxide and water; the animal cannot do this, but must depend upon the green plant directly or indirectly for its supply. Obviously this difference does not hold with those forms of plant life that contain no chlorophyll, such as the fungi, which resemble animals in their relation to food. 2. Another difference, which at first may seem to apply to all plants and animals, is concerned with *movement*. Animals, as we generally see them, move about freely, while plants seem to lack this power. This distinction is more apparent than real, for as one becomes more widely acquainted with plants, one finds multitudes of lower forms

that move freely, such as certain bacteria and some of the algæ. Likewise the leaves and floral organs of higher plants exhibit some power of movement. 3. Plant cells generally have well-defined, more or less rigid *cell walls composed of cellulose*; while animal cells either are naked masses of protoplasm or are surrounded by a firm layer very different from cellulose. Even this character, which seems to be the most general difference between plants and animals, does not hold with some of the lower forms.

THE PROTOZOA

General Characters. The minute *one-celled animals* that appear so abundantly in stagnant water and in the hay infusion, referred to in the study of bacteria, make up the phylum *protozoa*. All animals

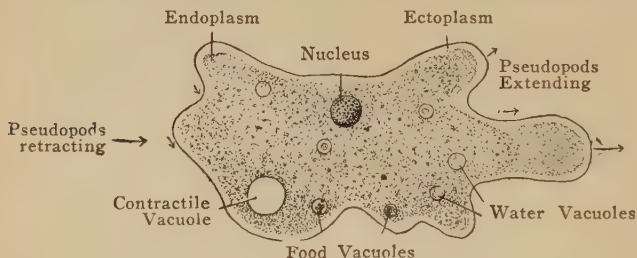


FIG. 165. — AMŒBA (From Colton's *Zoölogy*, page 286)

belonging to this group are extremely simple in structure. The body of one of the lower types of the protozoans, the *amœba*, consists merely of an irregular mass of colorless protoplasm, microscopic in size. Within the jelly-like body is a denser portion of the protoplasm, the *nucleus*. These animals are devoid of the cell walls found in plants and of the specialized organs which we associate with the complex animals.

A little higher in the group, protozoa, the protoplasm is somewhat differentiated, and certain definite structures appear, such as hair-like appendages that aid in locomotion and coils of stinging threads that are apparently used for defense. Still more complex forms consist of a number of cells attached to one another; in these, certain cells may take on some specific function, as that of reproduc-

tion. In the protozoans we have the beginnings of the specialized structures that are so prominent in the many-celled animals of the higher groups.

Occurrence of Protozoans. Protozoans in the active stages are found only *in water*, or at least in the presence of considerable moisture. If for any reason the water disappears, the animals pass



FIG. 166. — AN AMŒBA: Changes in form, drawn at short intervals.
(From Colton's *Zoölogy*, page 287)

into the inactive stage, in which they remain until conditions are again favorable for development. In these respects protozoans are similar to bacteria and other plant forms discussed in Part Two of this book.

Protozoans of different types are found in a variety of situations. The amœba, which is often studied, is frequently abundant in the slime on leaves and in other decaying materials at the bottoms of pools. Some of the free-swimming protozoans occur in the scum at the surface, and others are scattered through the clearer portions of stagnant water. Still other forms are present in moist soil, and some may be found even in the intestines and other animal organs. This is the case with some disease-producing species.

Life Processes of Protozoans. It is significant that these one-celled animals, simple as they are, carry on the fundamental life processes, such as movement, digestion, respiration, excretion, and reproduction, in much the same way as the most highly developed animals. For this reason the simpler protozoans are generally used to demonstrate the activities of the human body.

Movement in the Protozoans. Under the high power of the microscope, the slow movement of the amœba may easily be observed. The method of locomotion in this form is not entirely clear, but it seems to consist in a sort of sliding or rolling process. Portions of the semi-liquid protoplasm of the body are extended in

irregular lobes along the slimy leaf or other object upon which the animal is found. Into these projections, known as *pseudopods* or *false feet*, the main substance of the body appears to flow, giving rise to very slow but definite progress. In many of the higher forms of the protozoans where there are special *flagella*, or whip-like structures, which serve somewhat as oars, the movement is much more rapid. The same is true in regard to those having hair-like processes or *cilia*.

Digestion in the Protozoans. The food particles are taken directly into the protoplasm of the animal's body where, together with some water, they form a *food vacuole*. Here enzymes act

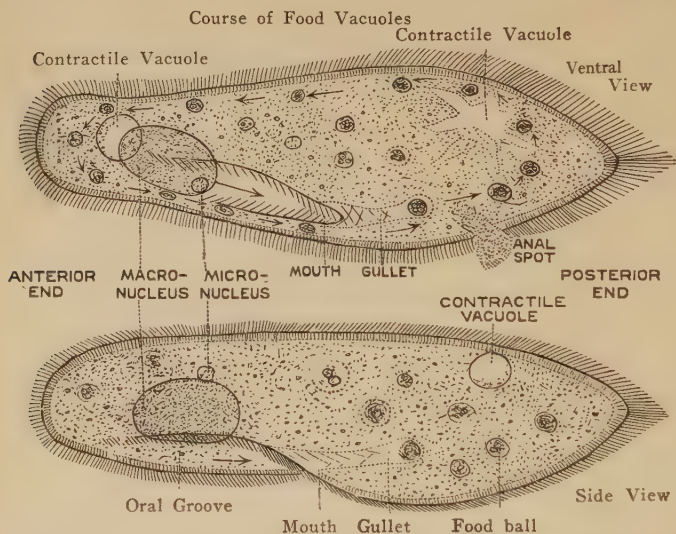


FIG. 167. — PARAMECIUM SHOWING STRUCTURES (From Colton's *Zoölogy*, page 292)

upon the foods in much the same way as in the human body, and the digested portions are used to furnish energy and to rebuild the protoplasm. The residues are returned to the surrounding water. In numerous parasitic protozoans the foods are absorbed directly from the body fluids of the hosts.

Feeding. In the amœba and other lower forms of the protozoans, the food substances may be ingested through any part of the surface of the body. The slow gliding movement of the protoplasm gradually surrounds the solid particles and carries them into the interior. In some of the higher forms, as the *paramecium*, for example, food is taken in at a certain point on the surface of the body and, after digestion, the residues are expelled at another definite place.

Respiration and Excretion in the Protozoans. The oxygen necessary for respiration is absorbed directly from the water into the living protoplasm, where it combines with food substances, thus releasing the energy necessary for the carrying on of the life processes. Essentially, this process is identical with respiration in higher plants and animals. The carbon dioxide and other waste substances produced, pass out directly into the surrounding water or collect in the *contractile vacuoles*, which, from time to time, break through the surface layers of the body and expel their contents. Thus *excretion* is accomplished in a very simple manner.

Reproduction in the Protozoans. In the lower types of the protozoans, such as the amœba, the animals often multiply by *fission*, apparently in much the same way as division occurs among

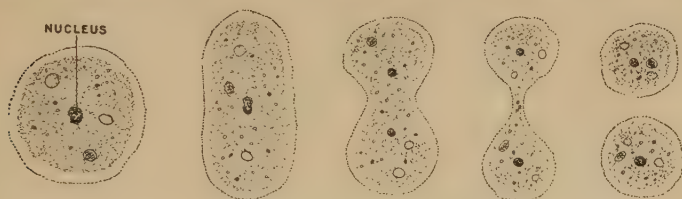


FIG. 168. — AMŒBA DIVIDING (From Colton's *Zoölogy*, page 289)

the lower algæ. The nucleus divides by mitosis (Page 97), and, at the same time, the surrounding protoplasm divides into two portions forming daughter cells that are approximately similar. These daughter cells increase in size and, in an hour or two, again divide. This explains why protozoans become abundant in stagnant water in such a short time. In some of the higher protozoans the division is

much more complicated than in the amœba. In some well known cases, there occasionally takes place a process known as *conjugation*, which strongly suggests fertilization as it occurs in higher forms of life. At the time of conjugation two individuals adhere to each other and exchange nuclear materials. After this occurs they separate, and multiplication proceeds as before. In a hay culture, numerous individuals of the free-swimming types may often be seen in conjugation.

In some protozoans the animals produce spores and thus give rise to a relatively large number of individuals, instead of producing only two, as is the case in fission.

Under unfavorable conditions, protozoans may go into the *resting stage*. If the surrounding water becomes insufficient, the bodies dry out and take on a resistant horn-like covering; and in this form the animals may live for a long time without injury. These dried bodies may be scattered widely by wind, animals, or other agents. Under favorable conditions of moisture and temperature, growth again takes place and active development proceeds. The facts just cited explain why protozoans are abundant wherever stagnant water is found.

Senses in the Protozoans. The power of protozoans to respond to various stimuli is significant. In these simple masses of protoplasm we find the beginning of the specialized senses, such as sight and touch, that are so well developed in higher animals. Even the simplest protozoans can distinguish between food particles and grains of sand. Some of the forms respond definitely to heat and light. The presence of oxygen in a bubble of air beneath a cover glass often attracts large numbers of the free-swimming types. There is also evidence that many protozoans are sensitive to contact.

The sensitiveness of these organisms to various influences appears to be due to the irritability of the protoplasm as a whole, rather than to specific structures. It is interesting to note that in the complex animals the senses have developed in connection with highly specialized organs, and that definite cells, as for example those of the retina of the eye, have taken over the function of perceiving definite stimuli.

Protozoans and Disease. A number of human diseases are caused by typical protozoan parasites or by organisms closely related to them. In fact there is a large group of these parasitic forms widely distributed in the intestines of higher animals, as well as in the blood and other tissues. Many of these types appear to do little or no harm, but others are responsible for a number of our most dangerous diseases. Such protozoans absorb their food directly from the body fluids in which they are found, and consequently are extremely simple in structure.

Tropical Protozoan Diseases. There are many tropical diseases of protozoan origin. *Sleeping sickness* carries off the natives of Central Africa by the hundreds of thousands. It has been said that "the destiny of the equatorial parts of Africa depends largely on the issue of the struggle of medical science against this haunting malady."¹ *Malaria*, which is much more serious in the warmer than in the cooler regions, is the most deadly of all maladies throughout the tropics. In Africa *relapsing fever* is reported to rank next to sleeping sickness as a scourge. Epidemics of this fever have been rather common even in western Europe. Early in the Great War, Serbia was visited by an unusually severe type. In the tropics there are also *diseases of the intestines, of the skin, and of other portions of the body*, that are due to protozoans.

Protozoan Diseases of Temperate Regions. Most of the diseases caused by protozoan parasites are found only in the tropics, but there are several in our own country and in other temperate regions throughout the world. *Malaria*, as it occurs here, although less deadly than the tropical forms, is very serious in low-lying swampy regions. In the past it has often rendered large tracts of valuable territory uninhabitable. A form of *dysentery*, a dangerous intestinal malady occurring in the southern states, is caused by a type of amœba. The human mouth often harbors amœbæ of several species, one of which has a close connection with *pyorrhea* and may possibly be the actual cause of the trouble. This disease affects the gums and the roots of the teeth, which become loose in the

¹ Reprinted by permission from *Animal Parasites and Human Disease* by Asa C. Chandler, published by John Wiley and Sons, Inc., New York.

sockets. An authority states that the loss of fifty per cent of all defective teeth may be attributed to pyorrhea. Another disease which has been serious at times in the southern states is *yellow fever*. The causative organism has not been determined with certainty, but there is evidence that it will prove to be a protozoan parasite.

Protozoans and Our Food Supply. Protozoans play an important rôle in the production of food used by higher animals. They, together with other minute organisms, make possible the existence of fishes, of mollusks, and of other aquatic species. The supply of the minute animals and plants referred to as *plankton*, determines definitely the quantity of fish that a stream can support. The large amount of fish furnished by the Illinois River is the direct result of the vast quantities of plankton that develop in the shallow water and wide marshes in and along the stream.

It follows that drainage of large areas and dredging will eventually cut down the supply of plankton and diminish the quantity of fish in a stream. Excessive amounts of sewage and waste products from factories may also prove to be a serious menace to the finer groups of game fishes.

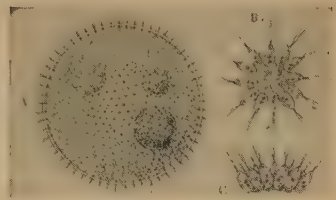
INTERRELATIONS OF PROTOZOANS AND OTHER ORGANISMS

The interrelations of the numerous minute animals and plants found in stagnant water give a clear idea of the constant struggle that has taken place for untold ages within and between the various groups of living things. The hay infusion referred to in the discussion of bacteria furnishes excellent material for the study of this subject. The water used should be from a pond or other source where the lower forms of life are abundant; otherwise some of the most important types may be lacking.

Bacteria and Protozoans. It has been pointed out that the organic matter from the hay furnishes food for the bacteria and nearly related forms, which develop rapidly and cause the infusion to become cloudy. These living organisms, together with particles of

decaying organic substances, constitute the food supply for types of very *minute* and *simple* protozoans, which, in a few days, are present in enormous numbers. These in turn are preyed upon by larger and more active types which soon become excessively abundant, only to be replaced by still larger carnivorous species.

Many-celled Animals. In the small jar of the hay infusion the succession of living forms is not yet complete. After the largest protozoans there may appear great numbers of minute many-celled animals, known as *rotifers*. The *rotifer* possesses a capacious mouth, consisting of an opening surrounded by



Volvox Gonium, top and side views

FIG. 169. — SIMPLE COLONIAL ORGANISMS (Magnified)

(From *General Biology* by Burlingame, Heath, Martin, and Pierce, Henry Holt and Company. By permission)

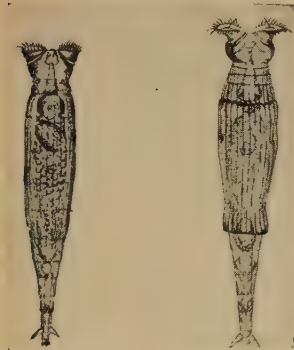


FIG. 170. — ROTIFERS (ENLARGED)

(Reprinted by permission from *Fresh Water Biology* by Henry B. Ward and George C. Whipple, published by John Wiley & Sons, Inc. By permission)

cilia. The cilia, which, in their vibrations, give the impression of rotating wheels, sweep the protozoans into the mouth. Besides the rotifers and related types, there appear sometimes minute *crustaceans*, belonging to the crayfish group, which likewise prey upon the lower organisms. In the small world of minute forms within the walls of the jar, the crustaceans often remain masters of the situation until they too disappear, as a result of the lack of suitable food or possibly of the accumulations of poisons in the water.

In a large aquarium the succession of forms may be carried much farther by the introduction of minnows and of mosquito and other aquatic insect larvæ.

Chemical Influences in Hay Infusion. During the shifting of the inhabitants of the hay culture, chemical changes continually

occur that doubtless play an important part in the succession of animals. It is very common for excretory substances to accumulate and become detrimental to the animals that have produced them. These chemical influences probably have more marked effects in the small quantity of water with which we are dealing than they would have in natural bodies of water.

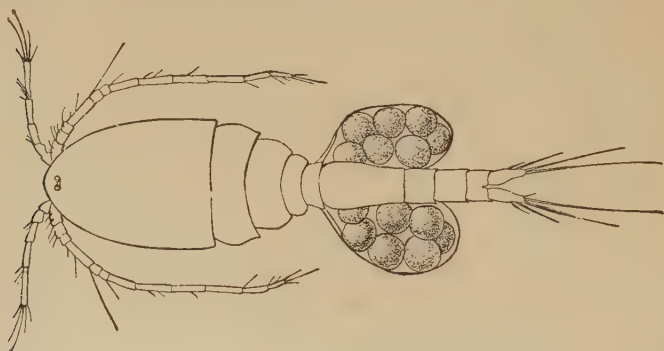


FIG. 171. — WATER FLEA (A crustacean) (From Colton's *Zoölogy*, page 84)

Plant Life in Hay Infusion. In a jar of stagnant water myriads of one-celled plants containing chlorophyll often appear. These may be of various types. Frequently the most abundant are the *desmids*, wonderful symmetrical forms of bright green color, and the *diatoms*, which contain brownish coloring matter and possess flinty, box-like shells of great beauty. Such plants, which make their own food and appear in enormous numbers in all natural bodies of water, constitute an ever present supply of organic matter suitable for nutriment of the lower animals. In the sea and in large bodies of fresh water where organic materials cannot be derived from the land, these microscopic plants are absolutely indispensable in the maintenance of many of the higher forms of life.

Interrelation of Living Forms in Natural Bodies of Water. The lower forms of life found in natural bodies of water are related to each other in much the same way as they are in the hay culture.

There are some differences, however, that should be noted. 1. In a river or a lake diatoms, desmids, and other forms of algæ generally supply the organic matter used as food by the simple animals. 2. The various animal types generally do not become abundant in nature and then largely disappear, to be replaced by another form, as is the case in the hay infusion. A sample of water from the shallow portion of a lake or river, for example, is very likely to contain a wide range of the simple animals, from the least complex to the more complex types. In nature, the struggle for existence between the various groups of animals goes on continually. A type that preys upon another form must be ever on the alert to escape its own enemies. The savage protozoan that eats his weaker brother must look out for the "terrible" rotifer. The great problem of life for these creatures is to *eat and not be eaten*.

The Part Played by Higher Animals in Large Bodies of Water. In the shallows along a river or on the margin of a lake, myriads of aquatic larvæ of the mosquito and of other insects feed upon the rotifers, the minute crustaceans, and the larger protozoans. All these forms, including the smaller larvæ of insects, make up the food supply of minnows and of the young of the larger fishes. In turn, the minnows, which rarely exceed three or four inches in length, as well as the young fishes, become the staple food supply of a large portion of the fishes of commercial value. Moreover, the smaller types of fishes used for human food become the prey of the larger species. The mammals of the sea, such as seals and walruses, the many land animals that feed upon fishes, and even man himself, enter into this remarkable succession of living forms that depend upon lower organisms for at least a portion of their food.

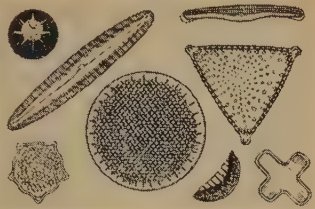


FIG. 172. — DIATOMS, ONE-CELLED PLANTS WITH FLINTY COVERINGS FOUND IN WATER (Magnified)

(From *General Biology* by Burlingame, Heath, Martin, and Pierce, Henry Holt and Company. By permission)

MANY-CELLED ANIMALS

Lower Types of Many-celled Animals. Tracing the succession of animals from the protozoans up to the vertebrates, or animals having backbones, such as fishes, birds, and mammals, we find a number of groups of varying complexity. Some are almost as simple as the protozoans, while others, earthworms and insects, for example, are highly specialized. These groups may be referred

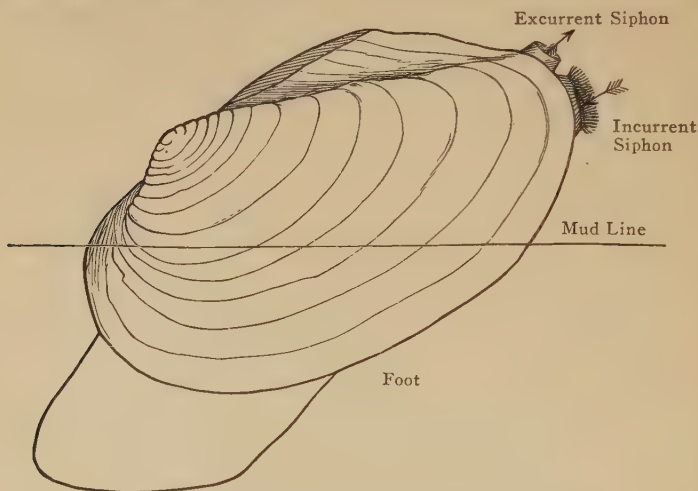


FIG. 173. — CLAM IN NATURAL POSITION WITH FOOT AND SIPHONS EXTENDED (A mollusk) (From Colton's *Zoölogy*, page 105)

to in a general way as *sponges*, *coral animals*, *starfishes*, *worms* of several distinct types, *mollusks* (such as clams and oysters), and *arthropods* (which include crayfishes, spiders, insects, and some other forms). Those species which are of far-reaching importance to mankind will be discussed in detail in the following pages.

Development of Specialized Organs as Illustrated in the Lower Groups. In the discussion of the protozoans, it was stated that the single cell carried on all the life processes, such as digestion, assimilation, respiration, excretion, and reproduction. It was also

pointed out that in the lower protozoans differentiation of structure is generally lacking, while among the higher ones a few special adaptations do appear, as for example, stinging hairs and reproductive cells. In the many-celled animals just above the protozoans, we find very definite specialization. Groups of cells adapted to perform specific functions, such as respiration and digestion, may be traced step by step from very simple beginnings in the lower forms to the very complex systems found in the higher many-celled animals.

Progressive Changes in the Digestive Systems of Animals. As we ascend the scale from protozoan to man we find the digestive system increasing in complexity. A discussion of these changes will give a general idea of the evolution of the circulatory, respiratory, excretory, and reproductive system as well.

The Need for Complex Organs. In the protozoans digestion is a simple process, for the formation of food vacuoles and the production of enzymes are accomplished through the activities of the general protoplasm of the animal cells. In the many-celled animals, or *metazoa*, the matter of providing food for the myriads of body cells increases in difficulty as the animal bodies become larger and more complex. To meet this need, the digestive, circulatory, and other systems must become more and more highly specialized.

Digestion in the Sponge. With the sponge, the simplest of the metazoa, there is no true digestive system. By means of cilia, food consisting of microscopic plants and animals is drawn in with currents of water through pores in the covering of the body. In some types, specialized cells along the canals connected with the



FIG. 174. — ONE OF THE SIMPLE SPONGES
(From Colton's *Zoology*, page 308)

openings, take in and digest the particles of food, as in the case of the protozoans. The digested portions then diffuse into the various cells of the body, where the food is utilized. There is no circulatory system.

Digestion in the Hydra. The hydra, a small water animal related to the coral-producing type, exhibits more definite specialization for the obtaining and digestion of food. This creature, which somewhat resembles a minute worm, attaches itself by the basal end to some solid object, such as a water plant or driftwood. Near the

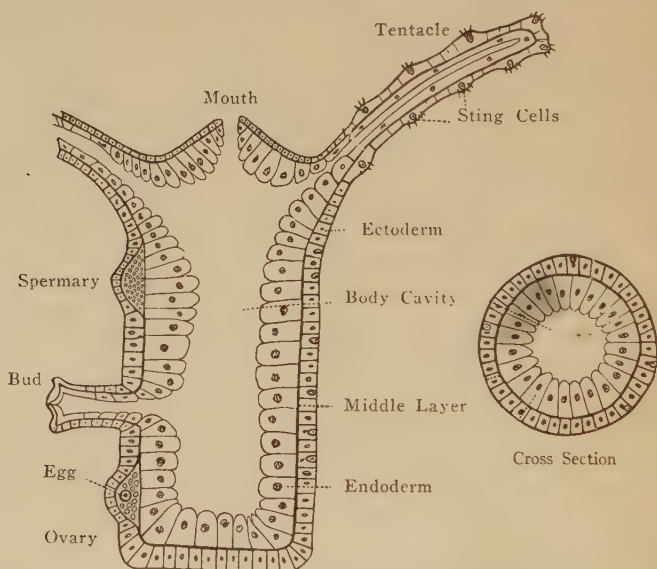


FIG. 175. — HYDRA, LONGITUDINAL SECTION (From Colton's *Zoology*, page 314)

center of the free floating end is a mouth, surrounded by a number of slender tentacles which are armed with numerous structures containing coiled stinging hairs. When a water flea, or some other animal upon which the hydra feeds, swims near, the tentacles discharge the coiled threads. These penetrate and benumb the victim, which is swept into the central cavity through the mouth opening.

The food is digested by the cells that line the interior cavity, and the products are diffused through the various tissues, where they are utilized. The undigested residues are ejected through the mouth opening.

Digestion in the Starfish. The starfish displays more complex adaptations than the hydra, for it has a definite *system* made up of several special organs. The *mouth*, which consists of an opening in the center of the "star," leads directly into the capacious *stomach*, which occupies a large part of the central interior region of the animal. A number of tube-like structures which secrete digestive fluids extend from the stomach out into the arms of the starfish. There is a short *intestine*, which also has a few *cæca*, or short tubes, attached to it, that are said to function as special organs of absorption.

Food and Process of Digestion in the Starfish. The starfish feeds upon various shell-fishes, such as oysters and clams. It fastens itself to the

clam, for example, by means of suckers on its arms, and exerts a steady pull which gradually opens the shell of its victim. As soon as the opening is large enough, the stomach of the starfish is passed out through its mouth and is applied to the body of the clam, and digestion begins at once. The digested food is distributed by a very imperfect system of blood vessels.

Digestive Organs of the Earthworm. The digestive system of the earthworm is still more highly specialized than that of the starfish. There is a very definite digestive tract that suggests in its complexity that of the vertebrates. The system consists of the



FIG. 176. — RED CORAL POLYPS, RELATED TO THE HYDRA

These animals produce the familiar coral. (From Colton's *Zoölogy*, page 329)

mouth, pharynx, esophagus, crop, gizzard, and intestine. There are also well developed glands that pour out digestive fluids along the food canal.

Process of Digestion in the Earthworm. The food of the earthworm consists of leaves and various organic particles that are obtained from the soil. These substances are taken into the mouth

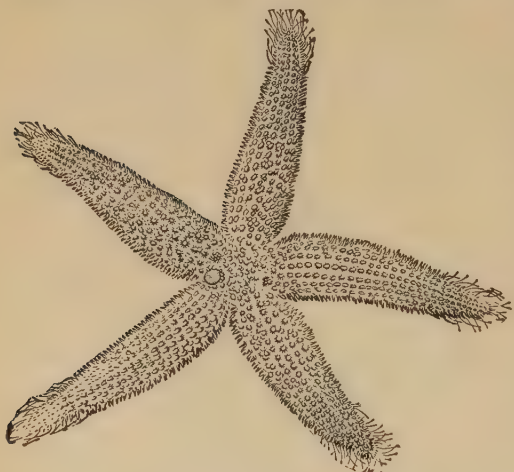


FIG. 177. — COMMON STARFISH (From Colton's *Zoölogy*, page 332)

and are carried through the pharynx and the esophagus into the crop, and thence into the gizzard. Within the gizzard are sand grains and small pebbles that have been swallowed by the worm. The action of the strong muscular walls of the gizzard grinds these hard substances together, thus reducing the food to a pulpy mass.

Throughout the ali-

mentary canal various glands pour out fluids which digest the food. The circulatory system that distributes the products of digestion to the tissues is much more complete in the earthworm than it is in the starfish.

Digestive Systems of Higher Animals. The digestive systems of crayfishes, insects, and other animals just below the vertebrates, also are complex and show interesting modifications. For the present, it is sufficient to point out that an increase in specialization in the various systems continues all along the animal scale, from the higher invertebrates, through the simple vertebrates, and up to the mammals. In this latter group, of which man is a member, the most complex systems of all are found. The gradual develop-

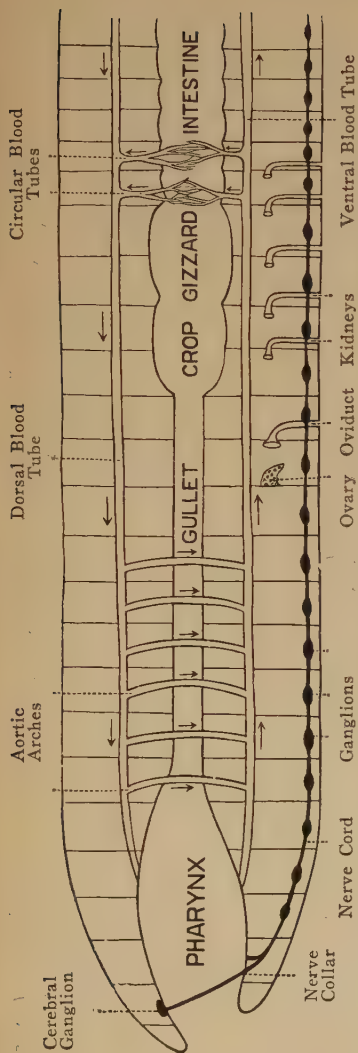


FIG. 178. — STRUCTURE OF EARTHWORM, SIDE VIEW (From Colton's *Zoology*, page 89)

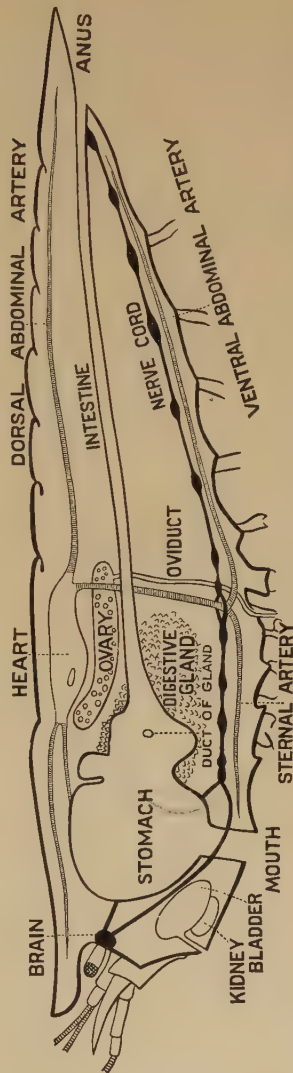


FIG. 179. — LONGITUDINAL SECTION OF A CRAYFISH, SHOWING DIGESTIVE, CIRCULATORY, REPRODUCTIVE, EXCRETORY, AND NERVOUS SYSTEMS. (From Colton's *Zoology*, page 65)

ment in the various structures and the fundamental similarity in the life processes of animals from protozoan to mammal *indicate unmistakable relationships between the various groups.*

SOME IMPORTANT LOWER ANIMALS

EARTHWORMS

Importance of Earthworms as Food for Animals. Earthworms fill an important place in nature, for they feed upon the abundant vegetable mold and other organic materials in the soil, and thus build up their own bodies which, in turn, form the food of many higher animals. Among these are several species of wild birds, domesticated fowls, fishes, and other vertebrates.

Habits of Earthworms. Earthworms live beneath the surface of the soil, where they form extensive burrows running in all directions. They eat not only the organic matter in the soil but also leaves and other plant and animal structures which are found upon the surface and are dragged into the burrows at night. As the food substances obtained beneath the surface are mixed with a large amount of indigestible particles, such as sand grains and small pebbles, great quantities of material must be taken in to provide sufficient nourishment. As a result, the refuse from the digestive tract is abundant. The food mass is passed through the intestine and the residues are voided in more or less worm-like "castings" at the mouths of the burrows. Everyone who has tended a garden or a lawn must have noted the rather extensive deposits of these "castings" wherever the soil is rich in organic matter.

Darwin's Work upon Earthworms. Many years ago Charles Darwin, one of the greatest biologists of all time, made extensive observations upon earthworms and discovered many important facts relative to their value in the soil. He found that the soil brought to the surface by these animals in many parts of England each year amounted to a layer a fifth of an inch in thickness. As a result of their activities, stones and other objects gradually became covered and finally disappeared from sight. He also observed that in the course of thirty years, a sterile field strewed with stones the size

of a child's head was converted into comparatively smooth and fertile pasture land, largely through the agency of earthworms. Through careful calculations he found that in many localities of England, "A weight of more than ten tons of dry earth annually passes through their bodies and is brought to the surface on each acre of land."¹

Earthworms and Soil Drainage. Earthworms are beneficial to the soil from the standpoint of drainage. As was pointed out in an earlier chapter, the water content of the soil is an extremely important factor in the growth and development of plants in general. A soil that does not drain well, and consequently becomes "water logged," does not produce well. The burrows of earthworms together with those of other small terrestrial animals, such as insect larvæ, aid greatly in carrying down the rain-water, that otherwise would either run off or remain on or near the surface and hinder the growth of many crop plants. Through the burrows the air may penetrate to the deeper layers of the soil and aid in the development of roots and in the process of nitrification.

Earthworms and Plant Food Elements. Earthworms are also of great value in bringing about conditions whereby plant food elements are made available. 1. The grinding together of the organic materials with the soil particles in the digestive tract, and 2. The transfer of soil from the deeper layers to the surface, where it is mixed with vegetable and animal remains, are processes highly beneficial to plant life. In this way, the insoluble soil particles which contain valuable chemical elements for plant growth are brought into intimate contact with the decaying organic matter and broken down into compounds suitable for plant use. (Page 158.)

TAPEWORMS

General Nature. The tapeworms comprise a rather extensive group of intestinal parasites that are widely distributed among the vertebrates. The various forms are quite similar in develop-

¹ From *The Formation of Vegetable Mold through the Action of Earthworms*, by Darwin, published by D. Appleton and Company, New York. By permission.

ment and structure. In general they require two hosts in which to complete their life cycles: in one the egg develops into an embryonic stage known as the *bladderworm*, and in the other the embryos grow to maturity and produce eggs. The more important

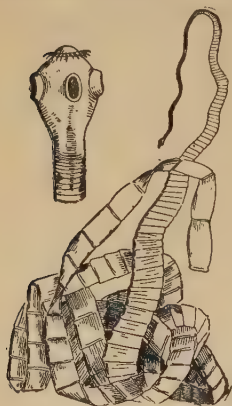


FIG. 180.—A HUMAN TAPEWORM Above—Head (enlarged) (From Colton's *Zoölogy*, page 349)

species of tapeworms have man as one host and cattle, hogs, fish, or even dogs as the other. There are also numerous forms that infest various carnivorous animals and their prey.

Structure of Tapeworms. On the whole, tapeworms are simple in structure. A typical adult tapeworm consists of a series of flat segments, known as *proglottids*, joined together to form a band sometimes many feet in length. The "head," which is small and simply constructed, is essentially an organ for attaching the parasite to the walls of the intestines of the host. This is accomplished in some types by a series of *bony hooks*, and in others by

sucking disks. Just back of the "head" is the comparatively narrow portion of the body, the "*neck*," which in the common forms consists of a large number of very small segments. As the distance from the "head" increases, the segments gradually become larger; for the new ones are formed near the "head" and continually press back the older ones, which continue to grow for some time.

Parasitism and Simplicity of Structure. The extremely simple structure of adult tapeworms is a result of their parasitic habits. Their bodies are in direct contact with the digested food substances within the intestines of the host, and absorption takes place through the body walls. There are no digestive organs whatever, and the other systems have also degenerated, with the exception of the reproductive and the excretory. Parasitism, wherein an organism depends upon another for its food and protection, usually leads to such degeneration.

Reproduction in Tapeworms. As has been stated, the re-

productive organs, which are absolutely essential to the life of the species, are comparatively complex. Each segment of the body develops both male and female organs. As the proglottids mature, fertilization occurs and immense numbers of eggs are formed that almost completely fill the posterior segments. These proglottids from time to time break off and pass from the body of the host, thus disseminating the eggs.

Life History of a Tapeworm. The beef tapeworm, which is said to be the commonest form that infects man in most parts of the world, serves well to give a clear idea of the remarkable development of these parasites. The eggs, which contain tiny embryos even before the ripe proglottids break off from the other segments, pass from the intestinal tract of the host in countless thousands. These eggs are scattered about by water or other means and finally are taken into the digestive tracts of cattle with the water or food. In the stomach or the intestines, the coverings of the eggs are dissolved and the minute larvæ which are released penetrate into the tissues of the animal and are scattered through the various organs by the blood and lymph.

In the muscles, the embryos rapidly develop into the *bladder-worm* stage, in which the body of the worm takes on a bladder-like form about a third of an inch long. The head is pressed in like a glove finger pulled in at the tip. Beef infected in this way is called "measly beef." When it is eaten by man, the bladder portion of the embryo is digested, the head attaches itself to the walls of the intestines, and rapid development begins. In due time the mature proglottids filled with eggs pass out of the intestine. Thus the life cycle is completed.

Damage to the Host. The common tapeworms, those from beef and pork, for example, affect the human host in several ways. Obstruction in the intestines, absorption of the digested foods of the host, the formation of ulcers in the intestines, and the possible production of poisons are some of the results found in serious cases. In one type of tapeworm, the adult stage occurs in the dog and the large complex bladderworms, known as "hydatids," occur in the liver or other internal organs of man. In various parts of the

world where men and dogs are closely associated, this type gives rise to a fatal disease.

Ridding the Body of Tapeworms. The treatment for tapeworms from beef and pork is very simple. First some drug is administered that either kills the worm or causes it to become detached from the intestinal wall, and then a purgative is employed to clear it from the intestines. Obviously the "hydatid" disease cannot be cured in this way.

Precautions against Tapeworms. The government which provides for inspection of the carcasses of food animals in the large slaughterhouses, aims to protect the public from tapeworms by detecting "measly" meats. If an animal is infected, the muscles of mastication and those of the heart are most likely to contain the embryos; consequently, these parts are systematically examined. It should be understood, however, that even with well regulated inspection, mistakes are likely to occur.

The certain method of prevention is *thorough cooking* of all meats where there is any possibility of tapeworm infection. A temperature of 127° F. is sufficient to kill the larval stages, but this temperature is not easy to obtain throughout a large piece of meat. Experiments show that a ham after two hours' boiling may acquire a temperature of only 115° F. at its center.

TRICHINA

General Characters. Another important intestinal parasite of man is the minute worm known as *trichina*. This worm, very different in structure from the tapeworm, also enters the intestines of man through infected meat. The disease caused by trichina is very serious, and moreover, it is of common occurrence wherever people are accustomed to eat pork that is not thoroughly cooked. According to one authority, not far from two per cent of the hogs in the United States are infected. Consequently, one of the very important purposes of government meat inspection is the detection of this parasite. This is by no means an easy task, for the larvæ are minute and may readily escape notice, especially where immense numbers of animals are slaughtered daily.

Trichina and Tapeworm Compared. Trichinæ and tapeworms are similar in a number of respects: both are parasitic in the intestines of vertebrates; both require two alternate hosts for perpetuating the species; and the larvæ of both forms are transmitted to man through infected meats. There is this difference, however, in the habits of the two worms: the tapeworm requires *two* distinct hosts in order to complete *one full life cycle*, while the trichina *completes one full life cycle* in the body of *each host*.

Life History of Trichina in the Hog. The larvæ of trichinæ gain entrance to the intestinal tract of the hog in the infected flesh of a rat or other animal. The embryos, which are generally present in enormous numbers, rapidly develop in the hog's intestines into male and female adults a sixth of an inch or less in length. The sexes mate and large numbers of minute young are produced. These active larvæ gain entrance to the blood vessels and lymph spaces, and migrate by the millions to the various muscles of the host. In the muscles the larvæ finally become encysted in connective tissue. They remain in this condition indefinitely, or until the flesh is eaten by another animal, in whose body the life cycle again commences.

Life History of Trichina in Man. These worms develop in man much as they do in the hog, but some additional facts will make clear why

the results in the human being are so serious. Apparently man is far more susceptible to the attacks of this parasite than most animals. In bad infections vast numbers reach the muscles of



FIG. 181. — YOUNG TRICHINA IN HUMAN FLESH BEFORE ENCYSTMENT Preparation made from the diaphragm. (Magnified)

(Reprinted by permission from *Animal Parasites and Human Disease* by Asa C. Chandler, published by John Wiley and Sons, Inc.)

the human body, especially those of the diaphragm, the ribs, the tongue, and the eye. The tiny larvæ, only about $1/250$ of an inch in length, thread their way through the muscles and finally enter the individual fibers.



FIG. 182.—TRICHINA ENCYSTED IN HOG MUSCLE The cysts were taken from infected sausage. (Magnified)

Reprinted by permission from *Animal Parasites and Human Disease* by Asa C. Chandler, published by John Wiley and Sons, Inc.)

Here they coil up into loose spirals and increase very rapidly in size to possibly a twenty-fifth of an inch in length. At this stage they keep up a slow writhing movement, which together with the waste products produced, brings about a degeneration of the muscle fibers. It is during this stage of the infection that the most serious injury to the patient occurs.

A few weeks after the parasite enters the body, cysts of connective tissue begin to form around the young worms within the muscle fibers, and they cease their activity. A few months later the cysts become impregnated with lime compounds and remain in the tissues unchanged for long periods. Sometimes the encysted larvæ die after a number of months, but cases are known where they have lived for eleven years in hogs and for as long as twenty-five years in man.

Prevention of Infection. The preventives employed against trichina are the same as those used for tapeworm infections. *Thorough cooking of pork used for food is the only certain means of avoiding the disease.* Inspection of meats should not be implicitly relied upon, for slight infections in a hog, which may produce serious consequences, often escape notice. In such cases a false sense of security really increases the danger.

Good results may be accomplished by keeping hogs in surroundings where they are not likely to gain access to the bodies of rats or other animals infected with trichina.

INTESTINAL WORMS

There are a large number of round worms that occur in the intestines of vertebrate animals. These vary in size from a foot or more to a fraction of an inch in length. Among them are several forms that often cause more or less serious trouble in the

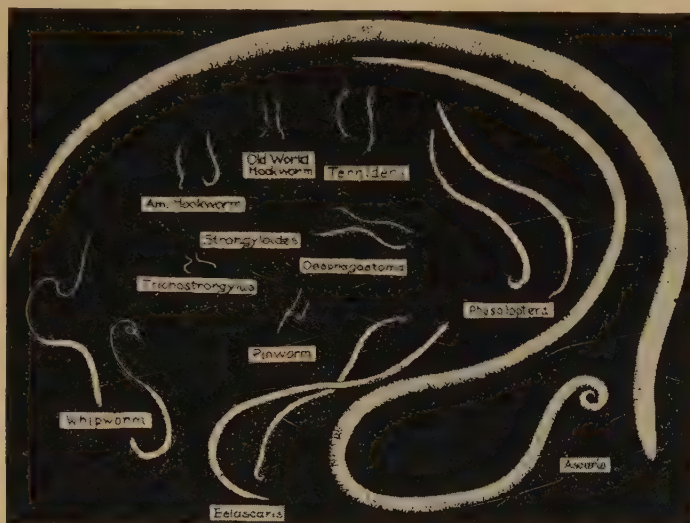


FIG. 183.—SOME INTESTINAL ROUND WORMS OF MAN (One-half natural size)

(Reprinted by permission from *Animal Parasites and Human Disease* by Asa C. Chandler, published by John Wiley and Sons, Inc.)

human digestive tract. In general, these types are propagated by means of microscopic eggs which are produced in enormous numbers and which escape in intestinal discharges from the bodies of the hosts. These eggs gain entrance to the intestines through polluted food or water, or by means of dirty objects that are taken into the mouth. Infections of this sort are very common among children, and among adults who live under unsanitary conditions where human refuse is not properly disposed of.

Hookworms. Hookworms are related to the types we have just mentioned; but the disease they cause has such far-reaching effects

in some regions, and the method by which they enter the body is so remarkable that a special statement concerning them is necessary.

In the southern part of the United States and in various tropical and semi-tropical countries, many millions of the population are infected with the hookworm. One authority states that possibly a half-billion people throughout the world are suffering from the disease.

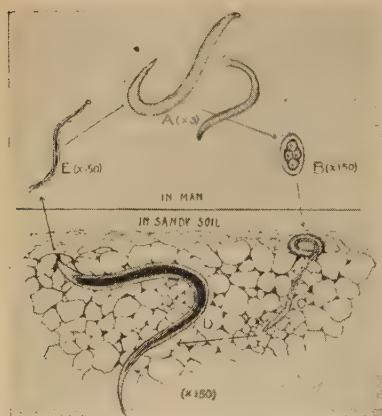


FIG. 184. — LIFE HISTORY OF THE HOOKWORM

(Reprinted by permission from *Animal Parasites and Human Disease* by Asa C. Chandler, published by John Wiley and Sons, Inc.)

Economic Loss from Hookworms. The effect of this parasite upon the victim is marked. The patient becomes anemic and weak, and loses all ambition. Before this disease was understood, he was looked upon as shiftless and lazy. In cases of long standing, the resistance of the body becomes so low that a comparatively slight illness from some other cause results fatally. Thirty per cent of all deaths in Porto Rico are said

to be due to the hookworm. In growing children, the disease hampers not only the physical but also the mental development. Because of the enormous number of people involved, and of the peculiar effects upon the individual, the economic loss to the world from this cause is almost beyond conception.

Habits of the Hookworm. These worms, which are about a half-inch long, attach themselves in great numbers to the walls of the intestines and suck the blood of the human host. Eggs are produced in prodigious numbers by the females and are carried from the body of the patient in the excrement. Rapid development takes place, and soon millions of tiny larvæ become scattered through the contaminated soil.

The larvæ gain entrance to the human digestive tract in a

remarkable manner. In warm regions where the hookworm thrives, many of the natives go without shoes, and the tiny larvæ penetrate the skin between the toes or in other regions of the body, and enter the blood capillaries. They are carried in the blood to the lungs, where they gain access to the air-tubes. Finally they appear in the throat and pass down with the food through the esophagus to the stomach and the intestines. It is said that this complex route is the chief, if not the sole way, by which the parasite enters the intestines.

Sanitation in Relation to Worm Diseases. The control of practically all of the intestinal worm diseases, with the exception of those contracted through meat, is to be accomplished through proper sanitary measures. So long as human excrement is disposed of on the soil or in other places where flies and dogs may come into contact with it, and where drinking water and foods, such as fruits and vegetables, may be polluted by it, worm diseases will continue to exist. It is a notable fact that in communities where sanitary conditions are good, troubles from worms are rare; while in regions where no attention is paid to the proper disposal of human waste, such diseases are of common occurrence. *The proper disposal of human sewage is the central problem in modern sanitation.* As the same measures employed in protecting water and foods from dangerous bacteria are used in preventing contamination from worms, they need not be restated here. (Review Chap. IX.)

CHAPTER XIII

INSECTS

GENERAL DISCUSSION

Insects and Their Relatives. Insects have much the same general structure as *spiders* and *ticks*, *centipedes*, and *crustaceans*. (The latter is the group to which crayfishes, lobsters, crabs, and a large number of smaller forms belong.) All of these animals are related to one another and have been placed in a single large group, the *arthropods*.

External Structure of Arthropods. The bodies of the arthropods are built up externally of a series of tough rings, called segments or *somites*, which form a hard outside covering, known as the *exoskeleton*. Like the bones in the higher animals, the exoskeleton serves for the attachment of muscles, and in many forms it affords protection for the organs beneath. The arthropods have characteristic appendages, which also possess the hard covering and are *definitely jointed*. The common crayfishes serve well to show the general characters of the group.



FIG. 185.—A SPIDER
(From Colton's
Zoölogy, page 56)

Comparative Importance of Insects. As crustaceans, spiders, and centipedes are only of indirect and, in most cases, of minor importance to man, they will not be discussed here. On the other hand, insects are very closely connected

with human welfare, and some knowledge of their structure and activities is absolutely essential in order to gain a clear understanding of their relation to man. Taken as a group, insects are among the most important animals on the face of the earth.

Injurious Insects. Many types of insects are extremely injurious from the standpoint of human health, while other groups cause enormous damage to crops and to domestic animals. They are often the chief and sometimes the sole agents by which many of our most dangerous diseases, such as typhoid fever and malaria, are spread. Consequently, if health is to be safeguarded, insects must be controlled wherever such diseases appear. The injury to



FIG. 186. — CENTIPEDE (From Colton's *Zoölogy*, page 54)

crops caused by insects is far greater than the loss from all other animals combined, and as a result man must constantly fight this horde of enemies in order to produce the food supply for the human race. A number of insects and related forms, such as certain flies and cattle ticks, carry diseases among domestic animals and injure them in other ways as well, thus affecting our clothing and food supplies.

Beneficial Insects. A large number of insects are beneficial to man. Some, like the honey bee and silk worm, produce valuable products. Moreover, insects in general form a part of the food supply of many higher animals, such as fishes, fowls, and wild birds. Certain groups, such as the bees and other nectar-feeding forms, are indispensable in the pollination of many plants. Probably the most outstanding service to man, however, is the work of a large number of parasitic and predacious insects that feed upon the injurious types and thus aid materially in holding these pests in check.

Kinds of Insects. Probably not far from a half-million different species of insects have been collected and classified, and doubtless vast numbers of other forms are yet to be identified, especially in those parts of the world not frequented by civilized man. Many different kinds may be found in a limited area almost anywhere in temperate or tropical regions. It is said that 15,000 distinct species occur in and about New York City alone.

Abundance of Insects. There are a great many different species of insects, and the abundance of a given species is often almost unbelievable. Countless millions of locusts, chinch bugs, army worms, scale insects, and others appear at times and destroy crops over extensive areas. The multitude of individuals in a species of insect is a result of their extreme rapidity of multiplication when food is plentiful and destructive agencies — such as birds, insect parasites, and diseases — are not present to hold them in check.

Characteristics of Insects. Insects are easily distinguished from the other arthropods by two well-defined characters:

1. The bodies of the adults are made up of three distinct parts: *head*, *thorax*, and *abdomen*. The head and the thorax are composed



FIG. 187. — GIANT WATER BUG (From Colton's *Zoölogy*, page 18)

of somites firmly united; the abdomen is made up of somites loosely joined together, which allow considerable freedom of movement. The head and thorax bear appendages. On the head are found *antennæ*, which serve as sense organs, and also various structures about the mouth which aid in the procuring of food. The wings and legs are attached to the thorax.

2. Adult insects generally possess three pairs of legs. In a few forms, such as the monarch butterfly, the front pair is much reduced and does not function, and in some others, the praying mantis, for example, this pair is definitely modified for grasping. In fact, the legs of insects perform many functions in

addition to that of locomotion. Other structures, such as wings and mouth parts, vary so much in the different species that it is difficult to make any general statements regarding these organs.

Digestion in Insects. The digestive organs of insects do not differ materially from those of the earthworm. There are some variations of minor importance, but in function the two systems are essentially the same. It is sufficient to note that insects that feed upon solid foods have alimentary canals adapted for the digestion of this material and are able, especially in the larval stages, to consume large quantities of it. Those that feed upon the juices of plants or upon blood have systems modified for the digestion of these substances.

Circulation. The circulatory system of a typical insect, such as the locust, is comparatively simple and consists of a tube-like structure that extends along the dorsal side of the body into the head. Valves permit the blood to pass only towards the anterior end of the body. The blood is forced into the head by the pulsations of this *dorsal vessel*, then it passes back through the irregular spaces in the tissues, and finally it re-enters the vessel ("heart") through small openings in the sides. Thus the circuit is completed. (The internal organs of an insect are visible in a mosquito larva mounted under low power.)

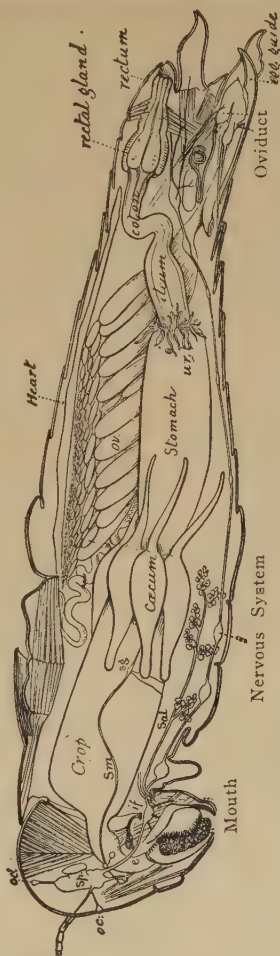


FIG. 138.—INTERNAL STRUCTURE OF A GRASSHOPPER (From Colton's *Zoölogy*, page 9)
oc, simple eyes; *sp*, brain; *e*, gullet; *if*, infra-esophageal ganglion; *sal*, salivary glands;
ov, ovary (eggs); *ur*, kidneys.

Respiration. The respiratory organs of an insect are a very extensive system of air-tubes, the *tracheæ*, that form a fine network throughout the body. The air-tubes communicate with the exterior through series of openings, called *spiracles*, located on the sides of the thorax and abdomen. In some insects the tracheæ connect with air sacs situated in various parts of the body.

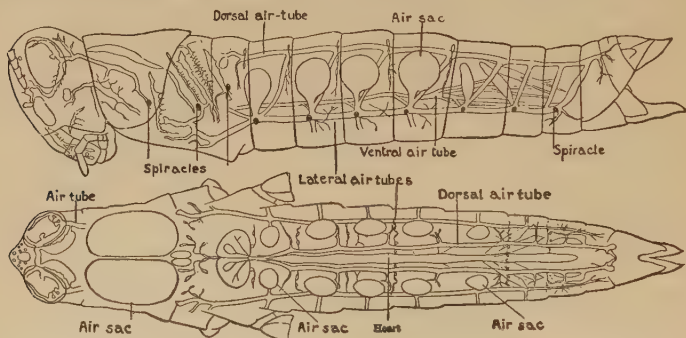


FIG. 189. — AIR TUBES AND AIR SACS OF GRASSHOPPER (From Colton's *Zoölogy*, page 6)

Respiratory and Circulatory Systems Contrasted. In the insects the tissues of the body obtain oxygen directly from the air in the tracheal tubes instead of from the blood supply, as is the case with man and other higher animals. Consequently, we find the simple circulatory and complex respiratory systems of insects in marked contrast to the complex circulatory and relatively simple respiratory systems of higher animals.

Excretory System. The body activities produce waste substances, such as carbon dioxide and nitrogenous compounds, in the insects in the same way as in other animals. It is likely that the carbon dioxide is eliminated largely through the tracheæ. The nitrogenous waste materials are excreted chiefly by means of the minute *Malpighian tubes*, which ramify through the tissues of the body. The excretory products from these tubes are emptied into the intestines and pass out with the food residues.

Nervous System. The nervous mechanism of insects consists essentially of a chain of *nerve centers*, or *ganglia*, distributed along

the ventral side of the body cavity. These ganglia are connected with each other by nerve trunks. The largest nerve center is in the head, and is sometimes referred to as the "brain," although it is nearer the truth to consider the entire string of ganglia as a structure which performs the functions of the brain of higher animals.

Reproduction in Insects. In general, insects reproduce by means of *eggs*, although *living young* are sometimes produced, as in many species of plant lice. In the blowflies, the young hatch either within the body of the mother or very soon after the eggs are deposited. In other cases, eggs are deposited in the fall and the young do not appear until the following spring. Some insects, such as the locusts, have but one generation per year; others, like the house fly, may have a dozen or more generations in a single summer.

The most conspicuous fact with respect to the reproduction of insects is the great rapidity with which they multiply under favorable conditions. Any injurious insect with an abundant food supply would become a serious pest in a short time, were it not continually held in check by its natural enemies, such as birds and other animals, and by disease and other destructive agencies. A good illustration of extreme rapidity of reproduction in insects is found in the house fly.

Development of Insects. The stages from the egg to the adult passed through by insects vary greatly among different members of the group. There are, however, two general methods by which this development takes place. These are of broad application to insect life as a whole.

1. With many insects, the young, as it hatches from the *egg*, bears little or no resemblance to the adult of the same species. This immature form, known as the *larva*, generally increases rapidly in size and in due time passes into a more or less perfect resting stage, known as the *pupa*, which differs in appearance from the larva and also bears little resemblance to the adult. Finally, the full grown *adult* emerges from the pupal stage. Insects that change *completely* from one stage to another during their development are

said to undergo *complete metamorphosis*. Good examples of this type are the blowflies, whose larvæ are called maggots, and the May beetles, whose young are the familiar grub worms. (Fig. 193.)

2. In contrast to the insects that pass through complete metamorphosis are the types that hatch from the eggs and bear a rather close resemblance to the adults except in size, in wing structure, and in a few other ways. These young insects develop by *gradual*

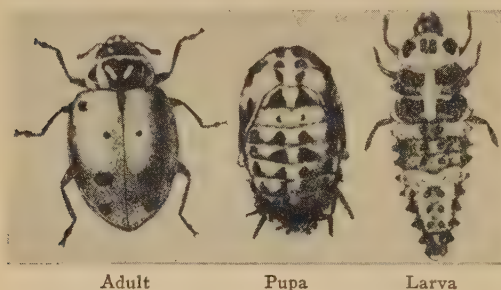


FIG. 190.—STAGES IN THE DEVELOPMENT OF A LADYBIRD BEETLE (Enlarged)

(Reprinted by permission from *Insect Pests of Farm, Garden and Orchard* by E. Dwight Sanderson, published by John Wiley and Sons, Inc. after Chittenden, U. S. Department of Agriculture)

changes through the larval stages, and become more and more like the adults until maturity is reached. They do not change completely from one larval form to another, and consequently such insects are said to undergo an *incomplete metamorphosis*. Good examples of this type of development are the

locust, whose young, known as *nymphs*, are abundant in the fields in late spring, and the squash bug, whose young may be found in all stages of development on pumpkin vines in early autumn.

Stages in the Development of Insects. The Egg. The eggs and the egg-laying habits of insects, even of those that are closely related, vary so widely that general statements regarding them cannot be made. A study of the individual types is necessary. Most insects, as they come from the eggs, are active and capable of taking care of themselves, and receive no attention from the parents. There are some, however, such as the honey bee, that are fed and protected by the adults through a large part of the larval stage.

Larval Stages of Insects. The larval stages are, in some respects, the most interesting and important in the development of

injurious insects. This is especially true of such types as potato beetles, cutworms, and cabbage butterflies, that ruin crops through the destruction of the leaves and other plant parts. The larvæ are also of great interest in the botflies and other insects whose young are parasitic in the digestive tract or other organs of higher animals.

Food Habits of Larvæ. The larval stages are the growing stages, and large quantities of food must be consumed to provide materials for this development. The rate at which many larvæ grow is almost beyond belief. A high authority states, "There

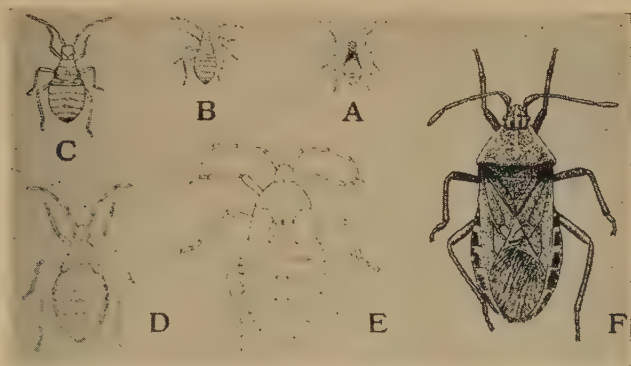


FIG. 191. — STAGES IN THE DEVELOPMENT OF THE SQUASH BUG

(From *Entomology* by J. W. Folsom, published by P. Blakiston's Son and Company. By permission)

are vegetable feeders, caterpillars, which during their progress to maturity, within thirty days, increase in size ten thousand times. To equal this remarkable growth, a man at maturity would have to weigh forty tons."¹ A brood of destructive caterpillars, such as those so common upon walnut trees in the summer, are practically microscopic when hatched; but they grow with such rapidity and require so much food that in a short time they not infrequently defoliate large trees. Another striking example of the voracity

¹ From *Useful Birds and Their Protection* by Forbush, published by Massachusetts Board of Agriculture, Boston. By permission.

of insect larvæ is found in the army worms, which have been known literally to eat up extensive fields of growing corn in a few days.

Pupal Stage of Insects. The pupæ of insects having complete metamorphosis stand out in striking contrast to the active and voracious larvæ. They do not take food and they do not move about; in many cases they are entirely quiescent. Consequently, little injury results directly from insects in this stage except in a few special cases, such as the Hessian fly, where the pupæ become lodged near the nodes in wheat and cause the stems to break at these points.

Development of Organs in the Pupæ. Many insects in the larval stages are adapted for the eating of very bulky food, such as green vegetation or other materials of this nature. The adults of these same forms in many cases feed only upon liquid foods, such as blood, nectar, and plant juices. Sometimes the adults take little or no food. Many moths and butterflies are examples of this change in diet; for the larvæ are generally leaf eaters, while the adults feed upon the nectar from flowers.

The modifications needed to fit the adult requirements take place in the pupal stage. During this resting period the internal organs of the larva are either broken up entirely or definitely modified; finally the organs of the adult appear. The food stored during the larval stages is drawn upon during these changes. Many external structures, such as the legs, wings, and antennæ, are also developed during the pupal stage.

Development of Organs Where No Pupal Stage Occurs. In those types that pass through incomplete metamorphosis, such as the squash bug, for example, both the young and the adult feed upon the same kind of food — in this case the juices of the pumpkin and related plants. Since there is no definite resting stage and the organs must function throughout the development of the insect, the changes from the young to the adult form must be gradual. There is no time when the digestive or other organs may be dispensed with and new systems constructed. Much the same general development takes place with the legs, wings, and other external structures of insects of this group. In the squash bug

the immature wings appear early and gradually change, becoming larger with each molt until finally they attain adult size.

The Adult Insect. The outstanding functions of the adult insect are reproduction and the dissemination of the species. With certain forms no food at all is taken and with some even life itself ceases as soon as the adults have accomplished these purposes. In many cases, however, the adults feed, but the amount eaten is often small compared to that consumed when the insect is in the larval stages. Adult insects, in general, do comparatively little damage through their feeding habits alone.

The tremendous amount of injury attributed to adult insects is due to two general facts: 1. The adults produce the young and disseminate the species far and wide, and 2. They are the carriers of human and other animal and plant diseases. The potato beetle, for example, would not be the serious pest that it is, if the adult were not so efficient in scattering the eggs wherever potatoes grow; nor would the house fly be considered such a dangerous pest if the adult were not a carrier of typhoid and other diseases.

The Importance of the Life History of an Insect. The life history of an insect includes its habits and its development. The character and number of the eggs, where and when they are deposited, the time when they hatch, the nature and food of the larvæ, the length of time it takes these to develop into the adult, and the habits and food of the mature form are matters of the highest importance relative to the control of injurious insects. The general method of attack is determined after a study of the life history has been made in as much detail as possible. The fact that malarial mosquitoes, for example, always breed in water, points definitely to the control of these insects through the destruction of the larvæ by the use of oil, of small fish, or of drainage. The life histories of a few typical insects will aid greatly in giving a general understanding of these forms and of their important relation to our food supply and to disease.

SOME TYPICAL INSECTS

LOCUSTS

Life History of the Locust (grasshopper). Locusts are excellent examples of insects passing through incomplete metamorphosis. The life history of one of our common forms in the Mississippi Valley, known as the differential locust, is quite typical of the group in general. The eggs of this species, which are deposited in the fall in the surface layers of uncultivated soil, hatch

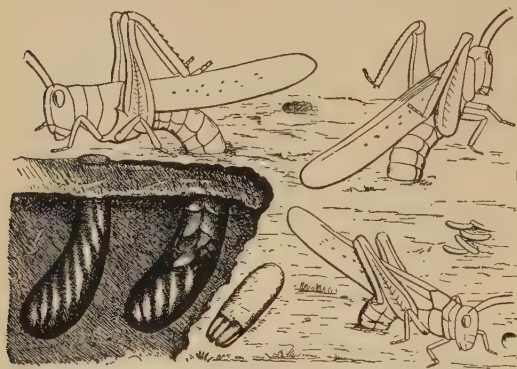


FIG. 192.—GRASSHOPPER LAYING EGGS (From Colton's *Zoölogy*, page 11)

in the Central States about the middle of May. The young locusts, known as *nymphs*, resemble the adults quite closely. The head is relatively large, the wings are lacking, and the legs are comparatively well developed, enabling the nymph to move about in search of food. Molting oc-

curs about five times during the first two months, and with each molt the insect becomes more and more like the adult. The body increases rapidly in size, the legs become larger, and in the later stages wing pads appear. After the last molt, the locust appears with the fully formed wings, legs, and other organs of the adult.

In molting, the hard external covering of the body splits along the dorsal side and the nymph within forces its way out through this opening, leaving the shed "skin" on grass stems or in other places where the process has taken place. Immediately after molting the nymph is very soft and unprotected, and it remains more or less secluded for a time; soon, however, the covering hardens and the insect again moves about freely and feeds voraciously.

While the body is soft, the young insect rapidly increases in size, but as soon as the exoskeleton becomes hard and resistant, growth ceases. During the rapid development described above, the nymph feeds upon various types of vegetation and at this stage often does considerable injury to crops.

Adult Locusts. The adult locusts also consume large quantities of food and, through their powers of locomotion, often spread rapidly over the fields. Some types may migrate for long distances, sweeping everything before them. This was the case with the Rocky Mountain locusts that visited the Central States in 1873-76.

The locusts mate in late summer. By means of their sharp pointed abdomens, the females make holes an inch or two deep in loose uncultivated soils, and deposit the eggs in them. The eggs become glued together through the hardening of a liquid that is poured upon them by the female at the time of laying. These masses remain in the soil over the winter and hatch the following spring.

Enemies of the Locust. Birds of many kinds, domestic fowls, predacious insects, as well as certain diseases, destroy vast numbers of locusts at all stages of their development. Were it not for the wholesale destruction of locusts by such agencies, the losses caused by them would be much greater than they are at present.

Control of Locusts. The methods devised to combat locusts illustrate well how knowledge of the life history of injurious insects aids man in fighting them. The cultivation of the soil where the eggs have been deposited to remain over the winter is effective in reducing the number of young that hatch the following spring; consequently, the plowing of soils in late fall after the eggs have been laid is a valuable practice in regions where locusts are destructive. Again, the young locusts generally feed in the open fields, in young clover and alfalfa, for example, and jump about very actively when disturbed; so a sheet iron trough, called a hopperdozer, that contains some kerosene or other insecticide is dragged through the fields, and the young locusts, hopping into this, are killed in large numbers. An authority states, "We have

known of from seven to ten bushels of young nymphs caught with one such pan in an afternoon.”¹ In some cases when the young are congregated in small areas, spraying the nymphs with poison has been effective. At other times poison bait made of bran and molasses, with some Paris green added, has been helpful.

MAY BEETLES

May beetles, or June “bugs,” as they are sometimes called, are among the most common of our larger insects. They are excellent representatives of the great group of beetles, the numerous species of which vary in size from those almost too small to be seen by the naked eye to certain tropical types several inches in length. May beetles may generally be found in abundance about electric street lights in late spring and in the summer. The general name, May beetles, refers to a considerable number of species all very similar in form and development, but differing somewhat in size and color. These beetles present us with a very good example of complete metamorphosis.

Life History of May Beetles. During the early part of the summer, the eggs of May beetles are deposited in the soil a few inches below the surface, and they hatch two or three weeks later, generally by the middle of July. The larvæ, which are the familiar grubs or “grub worms,” feed upon plant roots and grow slowly, attaining their full size in two or three years. During this long period of growth, the grubs burrow in the ground, and in the colder months they remain below the frost line.

These larvæ, often referred to as *white grubs*, sometimes do great injury to crops by cutting off the roots of grain plants and other grasses. At times these pests become so numerous in a given locality that it is possible to roll up the sod just as if it had been cut off a few inches below the surface with a spade or sod cutter. During a severe visitation of these insects in Illinois a few years ago, as many as thirty-four white grubs were found beneath a single hill of corn.

¹ Reprinted by permission from *Insect Pests of Farm, Garden and Orchard* by Sanderson, published by John Wiley and Sons, Inc., New York.

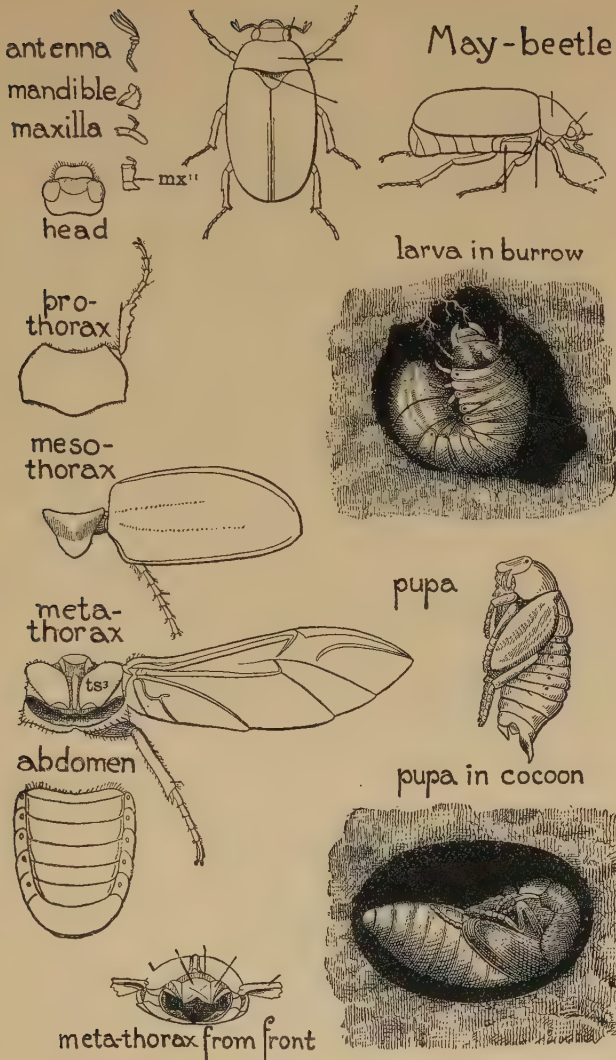


FIG. 193. — THE STRUCTURE AND DEVELOPMENT OF THE MAY BEETLE (From Colton's *Zoölogy*, page 37)

When the grub has attained its growth it passes into the pupal stage, and in about three weeks, usually in August or September, the adult wriggles out of the pupal skin and remains free in the soil over the winter. The following spring the fully matured adult comes forth from the soil and feeds upon the leaves of various trees, especially the forest species, and sometimes does considerable injury to shade trees. The eggs are then deposited and the adults die.

Control of May Beetles. May beetles are most readily destroyed in the larval or young adult stages. The young adults which remain near the surface of the soil over the winter may be exterminated in large numbers by deep fall plowing. In badly infested soils, hogs often root up and devour large quantities of the larvæ. Poultry that frequent freshly plowed fields also consume considerable numbers.

APHIDS

Aphids, or plant-lice, as they are often called, are exceedingly common insects and occur abundantly on the leaves and other green parts of a wide variety of plants. They are generally very small, plump-bodied creatures varying in color from light green to almost black. The light colored aphids are almost invisible when upon lettuce leaves or celery. They feed upon the sap of plants, which they obtain by inserting a very slender sucking tube into the plant. The life histories of these insects are so different from those already described and, moreover, they are so remarkable, that a brief account of the development of one of the numerous species seems advisable. There are many species of aphids of economic importance, but so similar is the development of the various forms that a description of one will serve to give a general idea of all.

Life History of the Apple Aphid. The apple aphid often may be found in abundance upon apple trees and sometimes upon pear and quince. The chief injury is done to young trees. The insects appear in very large numbers on the under surfaces of the leaves and cause them to roll up and fall, thus stunting the tree.



FIG. 194. — GREEN APPLE APHIDS

a. Injury to apple shoot; *b.* Spring migrant; *c.* Wingless female; *d.* Winter eggs on apple shoot. *e.* Pupa of spring migrant; *d.* (at right), *b.* and *c.* greatly enlarged.

(From *Farmers' Bulletin* 804, U. S. Department of Agriculture. By permission)

The minute, shining, black eggs of the aphids may be seen during the winter upon the apple twigs around the buds and scars. They hatch in early spring about the time the leaf buds are swelling. The young aphids obtain sap from the tender growing twigs and in two or three weeks become mature. All of these aphids are wingless females which, in a few days, give birth to living young (also all females) in large numbers. Some of the aphids of this generation develop wings, and, when mature, fly to other trees and serve to scatter the species. So the succession of generations continues until fall. About the time of the first frosts a generation is produced which consists of both males and females. These mate and each female deposits from one to three eggs that carry the species through the winter.

Interrelations of Cherry Aphids and Ladybird Beetles. The general relationship that exists between a given animal and an enemy that preys upon it is well illustrated in observations made in an orchard at Normal, Illinois, upon cherry aphids and a species of ladybird beetle. At the beginning innumerable plant-lice virtually covered the leaves in a growth of several hundred young cherry sprouts from the roots of old trees. Wandering through these multitudes of aphids were numerous adult beetles depositing eggs. On every young cherry sprout several of these ladybirds could be found.

A week later there were large numbers of young ladybird larvæ, small alligator-like creatures an eighth of an inch or a little more in length. These were feeding voraciously upon the apparently inexhaustible supply of aphids. At the third visit to the orchard a number of days later, a very remarkable situation became apparent. It was with some difficulty that a single living aphid could be found. The larvæ of the beetles had destroyed practically all of the plant-lice, or at least so many of them that living specimens were very scarce. Even more interesting than this, however, was the fact that there were large numbers of ladybird larvæ dying and dead for want of food. A few of the older larvæ that were fortunate enough to have attained their growth before the famine came, had passed into the pupal stage; but those that were born too late perished by the thousands.

So important is this relationship of living things that a brief summary of this particular case will be helpful. 1. The aphids had an abundant supply of food in the cherry leaves and, consequently, increased indefinitely. 2. When the aphids became numerous, the ladybirds which preyed upon them likewise multiplied rapidly. 3. There were soon so many ladybirds that they destroyed a large percentage of the aphids—in other words, they ate up their own food supply, and so they starved in large numbers. 4. The few scattered aphids that had escaped destruction by the ladybirds could then multiply and become abundant, again furnishing food in large quantities for the beetles. Thus in nature the cycle continues until some other factor, such as frost or disease, enters and breaks into the succession.

CABBAGE BUTTERFLY

The cabbage butterfly is one of the most destructive pests of our gardens. It was introduced into Canada about 1860, and in twenty years it had spread over all of the United States east of the Mississippi River. Its life history is especially interesting for study, for the various stages in its development may be obtained with ease in almost any garden during the latter part of the summer.

Life History of the Cabbage Butterfly. The eggs of the cabbage butterfly are deposited by the adults upon the leaves of cabbage or on some other closely related plant. There are several broods of this insect during the warm season, and adults may be seen at almost any time in late spring and in summer. The eggs hatch in from four to eight days into tiny, light green, velvety larvæ.

The larva at once begins to devour vast quantities of cabbage leaves and grows rapidly. At this stage the insects do great injury. In ten days or two weeks the larva attains full size and passes into the pupal stage, known in an insect of this type as the *chrysalis*. The chrysalis of this butterfly is something less than three-fourths of an inch in length and may often be found hanging on old cabbage leaves or on some other convenient object of support.

The adult butterfly emerges from the chrysalis in from one to two weeks in warm weather, but the period may be much longer in the cooler seasons. The young adults soon mate and produce the eggs for the next generation. In warm weather the whole life cycle from egg to adult may occupy only from three to five weeks. In the northern part of the United States there are about three

broods per season, but in the southern states there may be as many as six. The last brood of the fall remains in the chrysalid stage throughout the winter; the adults come out in the early days of the following spring. Thus the species is carried from one season to the next. These facts explain why "cabbage worms" in the North cause so little damage to the early crop and so much to the later crops, unless held in check in some way.

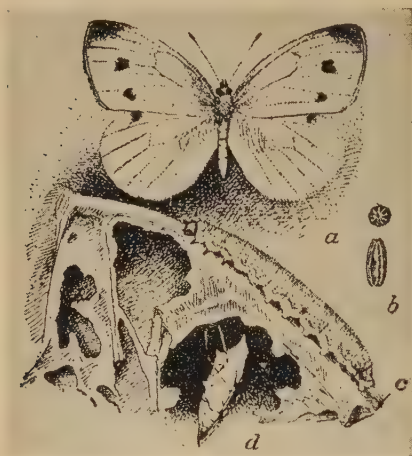


FIG. 195.—THE COMMON CABBAGE WORM

a. Female butterfly; *b.* Above, eggs seen from above; below, eggs seen from side; *c.* Larva or "worm" in natural position on cabbage leaf; *d.* Suspended chrysalis; *a*, *c*, and *d*, somewhat reduced; *b*, enlarged.

(From *Farmers' Bulletin* 766, U. S. Department of Agriculture. By permission)

Methods of Control of Cabbage Butterflies. In small gardens "cabbage worms" are sometimes picked off from the growing plants by hand, but this is not very satisfactory and must be re-

peated every day or two to be effective. The practice known as "clean gardening" is of value in the control of these pests as well as of other injurious garden insects. It consists in collecting and burning the old stumps of cabbage and other garden rubbish in the fall, and then plowing the land. As a result, the insects that winter in such materials are destroyed. The most effective method for the control of this pest, however, is the spraying or dusting of

Paris green or lead arsenate upon the plants. This treatment is inexpensive and gives excellent results. The poisons are applied to the plants before they are headed, and when used in this way are not a source of danger.

It has been shown that a person would have to eat twenty-eight cabbage heads at a meal in order "to secure poisonous effects."

Natural Enemies of Cabbage Butterflies.

It is fortunate that the natural enemies of these pests often hold them in check. Insectivorous birds, certain wasps, and some predacious bugs have a considerable part in this good work, but by all means the most effective are a number of tiny parasitic insects that prey



FIG. 196. — AN ICHNEUMON FLY THAT PARASITIZES THE CABBAGE WORM

a, adult; *b*, cocoon; *c*, flies escaping from the cocoons; *a*, *b*, Highly magnified; *c*, slightly reduced.

(From Chittenden, U. S. Department of Agriculture. By permission)



FIG. 197. — PARASITIZED CABBAGE WORM SHOWING COCOON MASS OF THE ICHNEUMON FLY ILLUSTRATED ABOVE (From Chittenden, U. S. Department of Agriculture. By permission)

fly, which attacks the larvæ of the cabbage butterflies. The tiny maggots live within the body of the host, where they destroy the tissues and cause the death of the larva. When full grown, they emerge from the body and spin tiny cocoons on the outside. The clusters of cocoons, together with the dead larvæ, often may be found in late summer upon cabbage leaves. It is said on good

the most effective are a number of tiny upon the larvæ. Two of these will serve well to illustrate how parasites aid in the control of insect pests.

The Control of Cabbage Butterflies by Parasites.

Two parasites, which are very common in late summer, often may be obtained in great numbers from diseased "worms" or from the chrysalid cases. The most important is a small wasp-like insect, known as a *braconid*

authority that during the autumn of 1904 this parasite killed practically every cabbage worm at Washington, D. C. Another important parasite is a tiny *chalcis-fly*, only a sixteenth of an inch long. This also attacks the larvæ of the cabbage worm. The adults of this parasite, however, are likely to emerge from the chrysalid cases of the butterfly in great numbers, sometimes hundreds from a single specimen. On one occasion the author was unable to find, even after long search, a single chrysalis that had not been destroyed by the chalcis-fly.

PARASITIC INSECTS

The General Nature of Parasitic Insects. So important are parasites in the control of injurious insects that some understanding

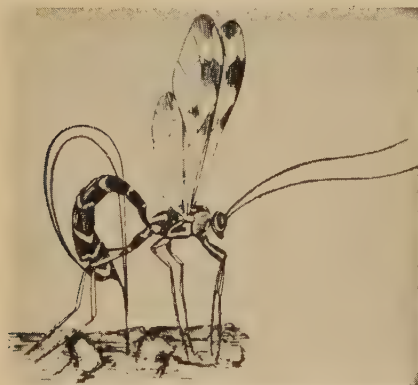


FIG. 198. — A LARGE SPECIES OF ICHNEUMON FLY DRILLING A HOLE IN A TREE TRUNK IN ORDER TO DEPOSIT ITS EGG IN THE BODY OF A CERTAIN WOOD BORING LARVA (About natural size)

(From *American Insects* by Vernon Kellogg published by Henry Holt and Company. After Comstock. By permission)

of their general nature is essential. The larvæ of the parasitic forms generally live within the bodies of the hosts, where they subsist upon the tissues and cause death, as indicated above. Sometimes the eggs of parasitic insects are deposited upon the body of the host, and the young, upon hatching, penetrate into the interior. In a large number of cases, however, the eggs are thrust into the tissues of the host by the adult female through the use of the *ovipositor*, a structure at the tip of the abdomen that is

adapted for this purpose. In some parasites of domestic animals, in the botflies, for example, the eggs are attached to the hair

or are deposited in the nostrils, allowing the young to gain entrance to the interior of the host by way of the mouth or nasal passages.

Larvæ Most Often Parasitized. Parasites that feed upon insects usually attack the host in the larval stages, although at times the adults or even the eggs may be parasitized. When the host is attacked in the early development period, death ensues in a large majority of cases before the adult appears. Sometimes a larva that has been parasitized may pass into the pupal stage, but the development of the host is rarely completed.

Short Life Cycle of Parasitic Insects. One of the outstanding characteristics of parasitic insects is the rapidity with which they develop. This rapid growth is made possible through the abundant supply of food, which consists of the host's blood and other body fluids that are ready to be absorbed by the young parasites. The eggs may be deposited upon or within a half-grown larva, and yet so rapid is the development of the parasites, that before the host completes the larval stage, the parasites may complete their entire life cycle and emerge as adults. It is probable that the presence of the parasites retards the development of the host. In late summer this condition may be easily observed in the larvæ of certain sphinx moths, or tomato "worms," as they are called. Half-grown "worms" of this sort often are literally covered with the tiny white cocoons of a parasite that preys upon this insect. (Fig. 200.)

Effectiveness of Parasites. Parasites that attack insect hosts are often very minute, and reproduce very rapidly. This is illustrated by the chalcis-fly, discussed in connection with the cabbage butterfly. The short life cycle, and rapid multiplication are two outstanding factors that enable these parasites to be so destructive.



FIG. 199. — AN ICHNEUMON FLY DEPOSITING ITS EGGS IN A COCOON OF A MOTH (From Weed's *Farm Friends and Farm Foes*, page 174)

Definite Hosts for Definite Parasites. Most insect parasites are limited to one, or at most, to a very few different hosts. The



FIG. 200.—LARVA OF A HAWK MOTH WITH COCOONS OF A PARASITIC ICHNEUMON FLY ATTACHED (From Colton's *Zoölogy*, page 51)

parasites of the cabbage "worm" apparently are not able to parasitize other insects even though the larvæ may be quite similar

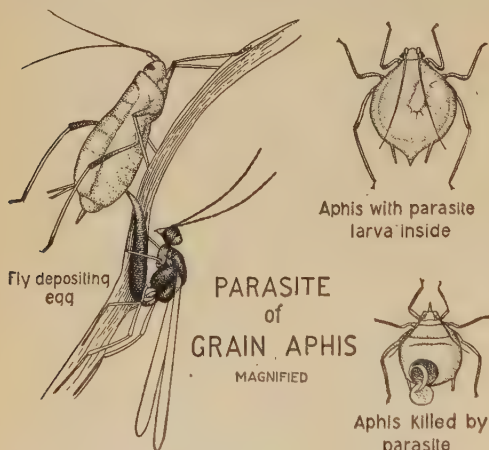


FIG. 201.—(From Weed's *Farm Friends and Farm Foes*, page 179)

to those of the cabbage butterfly. There may be myriads of these parasites present, but they rarely, if ever, attack other insects to any considerable extent. This results in a very striking relation between a parasite and its host.

Relation of a Parasite to Its Host.

If the parasite is abundant enough to kill off a large proportion of its hosts, then the parasite itself will lack food and a great many will die. When this takes place, the relatively small number of host insects that es-

caped again increase, for the parasites are too few to control them. With the food supply replenished, the parasite again multiplies and destroys the host. In this way the two forms of life virtually hold each other in check. The relation is even more complicated than this in nature, for other agencies enter that disturb this comparatively simple warfare.

Man sometimes introduces an insect into a new region where it has no natural enemies, and thus he brings upon himself untold injury. Such was the case with the fluted scale, an insect from Australia, and also with the cabbage butterfly at its first appearance in America, before its natural enemies became abundant. (Page 403.)

Kinds of Parasitic Insects. There are a great many different kinds of parasitic insects, but the group as a whole is well known only to specialists. This is chiefly owing to the fact that many of these forms, being minute, escape notice except when they appear on the larva or pupa of some larger insect that is being observed. On the other hand, some of these parasites are compara-



FIG. 202.—A TACHINA FLY

This insect parasitizes army worms, gypsy moths, and other destructive pests. (From Weed's *Farm Friends and Farm Foes*, page 190)



FIG. 203.—CHALCID FLIES (Much enlarged)

(From *American Insects* by Vernon Kellogg published by Henry Holt and Company. After Howard. By permission)

tively large, as for example, the ox warble, the botfly, and the ichneumon fly, which is related to the wasps and in some cases is from one to two inches in length.

Groups of Parasites. Most parasitic insects are allied to bees and wasps. In this extensive group there are several large families composed exclusively of insects of this type. A considerable number of parasitic forms are also found scattered through the group to which flies and mosquitoes belong.

Interrelations of Parasites to Each Other. The complexity of the relationship existing between animals in general is further illustrated by the insect parasites. Insects that parasitize a given host, generally a vegetable feeder, — for example, the tomato “worm,” — are spoken of as *primary* parasites. The smaller parasites that attack the primary parasites are referred to as *secondary* parasites. Remarkable as it may seem, other forms known as *tertiary* parasites, sometimes parasitize the secondary parasites. If the primary parasite is beneficial, the secondary is injurious; but if the primary is injurious, then the reverse is true of the secondary, and the tertiary is also injurious. Someone has expressed this remarkable relationship in an inaccurate but amusing fashion as follows:

“Great fleas have little fleas,
Upon their backs to bite ’em,
And little fleas have lesser fleas,
And so *ad infinitum*.”

INSECTS AND DISEASE

The importance of the transmission of disease by insects can scarcely be overestimated. The germs of a number of the most dreaded maladies are carried in no other way; and those of many other diseases are transmitted at least in part by insects. A discussion of house flies and mosquitoes will serve well to illustrate this method of germ transmission.

House Flies and Disease. In temperate regions house flies are the most active insects in the transmission of disease. The germs of typhoid fever and a number of other filth diseases are among those commonly carried in this way. Of especial importance during the warm weather are the intestinal diseases of children

formerly referred to as "summer complaints." There is evidence that more than a dozen human maladies are spread partly by the activities of house flies.

The germs are carried on or within the body of the insect in a purely mechanical way. The organisms do not go through any definite development within the body of the fly as is the case with the malarial parasite in the mosquito. They are simply transported from the filth to human food or to the hands or lips, from which they rapidly gain entrance to the digestive tract.

It may be said, without danger of contradiction, *that the house fly, which has access to filth contaminated with the germs of serious human diseases, is the most dangerous animal from the standpoint of human welfare with which civilized man has to deal.*

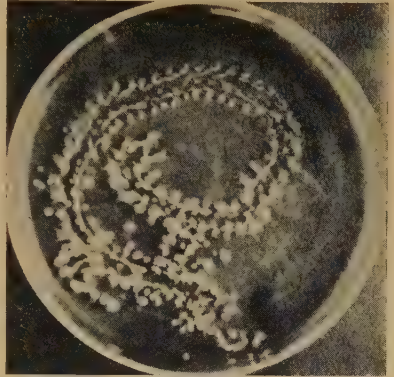


FIG. 204. — PETRI DISH SHOWING BACTERIA DEVELOPING FROM FLY TRACKS

(From Howard, *The House Fly*. Photograph by William Lyman Underwood. By permission)

Life History of the House Fly. The eggs of the house fly are generally deposited upon stable refuse, but other types of filth or decaying material may at times be used for this purpose. A single female may produce six hundred eggs during the laying period. In warm weather these hatch in a few hours, and the larvæ, known as *maggots* burrow below the surface and feed upon the decaying substances. The young maggots grow rapidly, and in the summer they attain full growth in less than a week, and pass into the pupal stage. In from five to seven days, they emerge as adults. Thus, under advantageous conditions, the whole life cycle may be covered in less than two weeks.

Food Habits of the House Fly. The dangerous character of house flies in regard to the scattering of disease germs is due largely

to their peculiar habits of feeding. They are primarily filth insects, feeding on all sorts of accessible decaying material. If this were the whole story, flies would be no more harmful than many other insects of like habits; they might, in fact, be considered beneficial.



FIG. 205.—HOUSE FLY LARVÆ IN REFUSE
(Reduced)

From Newstead. Reprinted from *The House Fly* by L. O. Howard. By permission)

From the filth, house flies go more or less directly to human habitations and crawl over the food or fall into the milk, carrying to these substances any bacteria that may be adhering to their feet or to other portions of their bodies. If the bacteria are harmless—that is, if the flies have not been in contact with filth contaminated with human disease germs,—then the danger is

not serious, although the presence of the insects may be disagreeable.

Proper Disposal of Sewage. It is very important to understand that the *primary error, from the standpoint of sanitation, consists in the careless disposal of human wastes in situations so exposed that flies may become contaminated with the dangerous bacteria of intestinal or other human diseases.* It is certainly a wise precaution to destroy flies by every known means; but it is *equally important to educate the general public relative to the proper disposal of human sewage*, so that it may be impossible for these insects to come into contact with such materials.

Method by which Flies Carry Bacteria. There can be no question that house flies often carry immense numbers of bacteria and scatter them over foods and other substances. Reliable experiments have shown that flies caught in the vicinity of garbage cans, or in other situations where bacteria are abundant, may literally be covered with millions of these organisms.

The external structures of flies are adapted in a striking way for the carriage of germs. Practically the entire body is covered with

fine bristly hairs that doubtless aid greatly in holding infected materials; but the mouth parts and the feet are the most remarkable from this standpoint. The complex character of the mouth parts, the microscopic bristles with which they are covered, and the manner in which they are used for obtaining food render them very effective as germ carriers. The feet also are covered with rather coarse bristles, and each is provided with two tiny pads composed of sticky microscopic hairs. These structures come into contact with the substances upon which the fly walks and, obviously, are very efficient in collecting and scattering germs. (Fig. 207 and 208.)



FIG. 206. — PUPÆ OF HOUSE FLY ON ROTTING CLOTH FROM AN ASH BARREL (Reduced)

(From Newstead. Reprinted from *The House Fly* by L. O. Howard. By permission)

The Destruction of House Flies.

The extermination of house flies is one of the most important phases of any campaign for the betterment of health conditions in the average American community. This is most effectively accomplished through the destruction of the possible breeding places. Fly traps, poisons, and tangle-foot paper are helpful in clearing the adult insects from a room or some other limited space. These methods, however, are entirely inadequate in the open, so long as stable refuse and other decaying materials in the vicinity offer suitable breeding places. If house flies are to be controlled, *their breeding places must be destroyed.*

Breeding Habits and Animal Control. It is a well-recognized principle in nature that *interference with the breeding habits of an animal is by far the most effective way to annihilate the species.* The destruction of house flies through the removal of breeding places is an excellent example of the application of this general rule. This general principle is just as applicable to the higher animals as it is to the insects. The most certain method of

limiting the abundance of food fishes, for example, is to cut off the food supply of the young or to prevent the laying of the eggs. Likewise, the destruction of the nesting sites of birds is a most effective way for diminishing their numbers.

The Same Principle Applies in General to Reproduction in Plants. With these forms, however, the interference is with seed or spore production, and with the early stages of germination. The constant fight against many types of weeds is based either upon the prevention of seed production, or upon the destruction of the plants when in the seedling stage. Influences that interfere with



FIG. 207.—FOOT OF HOUSE FLY
(Enlarged)

(From *American Insects*, by Vernon Kellogg, published by Henry Holt and Company. By permission)

the plants during the early stages of germination produce effects that are often permanent, for young plants, as well as young animals, are very sensitive to injurious conditions in the early developmental period.

Mosquitoes as Disease Carriers. Most of the mosquitoes found in the United States are harmless so far as the transmission of disease is concerned. Certain types, however, belonging to the group *Anopheles*, are known to transmit

the germs of malarial fever. In fact, there is much evidence that the various forms of this disease are disseminated in no other way. Unlike the house flies, the mosquitoes transmit the disease germs through their bites. Yellow fever is also carried by these insects, but another type of mosquito, the *Stegomyia*, is the agent.

Development of Malarial Germs in Body of the Mosquito. The malarial organisms pass through a very definite and apparently necessary period of their life cycle in the body of the *Anopheles* mosquito. The germs reach the digestive tract of the insect in the blood that it sucks from a malarial patient. In the stomach these organisms pass through a sexual phase that results in myriads of very minute spores, which find their way into the body fluids and finally reach the salivary glands of the mosquito.

These glands are located in the head and are connected with the sucking beak.

Transmission of the Germs. After this development, which requires several days, the insect can transmit the malarial germs to human beings. When a person is bitten, a very small portion of saliva is forced into the wound, and the spores contained in it may develop and give rise to the disease in this individual. Anopheles mosquitoes that bite this patient transmit the disease to other persons, and thus the cycle continues.

Life History of the Mosquito. The life habits of the numerous species of mosquitoes are, in general, quite similar, the differences being only in minor details. Our commonest form, the *Culex*, serves well as a representative of the whole group. Though annoying to man, this type is entirely harmless from the standpoint of disease transmission.

During warm weather the females of the *Culex* mosquitoes deposit their eggs upon standing water in boat-shaped masses. These eggs are produced in large numbers, a single female laying from two to four hundred. The boat-shaped mass floats about on the water, and, in warm weather, the eggs hatch in less than a day into the tiny larvæ or *wrigglers*, as they are sometimes called. These are often abundant in rain barrels, cisterns, and in small pools. The wrigglers are active, "large-headed" creatures, which feed upon particles of organic materials obtained from the water. The breathing tubes extend through the body and terminate in a pointed structure near the end of the abdomen, which projects above the surface of the water from time to time, allowing air to enter the spiracles. (Fig. 209.)

The young larvæ grow rapidly and, in warm weather, change into



FIG. 208. — MOUTH PARTS OF THE HOUSE FLY (Much enlarged)

(From *American Insects* by Vernon Kellogg published by Henry Holt and Company. By permission)

the pupæ, also "large-headed" creatures, in from seven to ten days. These rest at the surface of the water, but, unlike the larvæ, they have the anterior end in contact with the air. The pupa of a mosquito does not take food, but it differs from the typical resting stage of most insects by being active. In two or three days the pupal "skin" splits along the dorsal surface and the adult mosquito appears.



FIG. 209. — LIFE HISTORY OF A MOSQUITO

(From *American Insects* by Vernon Kellogg published by Henry Holt and Company. By permission)

The entire life cycle of the mosquito in warm weather may occupy only ten days — a fact that explains why these insects often become so abundant after rainy spells in the summer, when water stands in old cans, eave troughs, or horse tracks for a period of ten days or longer. As mosquitoes never fly more than a few hundred yards from the place where they develop, any visitation of these insects near a dwelling is generally due to standing water somewhere in the immediate vicinity.

Methods of Combating Malaria. The most successful method known for checking epidemics of malarial fever, in districts where it is prevalent, is the destruction of the *Anopheles* mosquitoes. Yellow fever is also controlled by the extermination of the mosquitoes (*Stegomyia*) that disseminate this disease.

Destruction of Mosquitoes. In general, mosquitoes are destroyed in one of three ways. 1. If feasible, the breeding places are drained. In regions of heavy rainfall, it is often difficult to carry out this method with complete success, even where the slope of the land makes drainage easy. Pools of water are likely to form

in low places during periods of rainy weather and remain long enough for the breeding of mosquitoes. Notwithstanding the difficulties to be overcome, this practice has been beneficial, even in swampy localities. In such regions large areas are often drained and used for agricultural purposes. 2. Probably the most prevailing method for the destruction of mosquitoes is the spraying of non-volatile oils upon the pools of water. A coating of this sort upon the surface is very effective in destroying mosquito larvæ, for, when they rise to the surface to breathe, they come into contact with the oil and are speedily killed. Obviously, on account of its objectionable character, there are many places where oil cannot be used. 3. Another method of combating mosquitoes in park lakes, and in fountains is the use of small fishes. In permanent pools this practice is very effective. Minnows and young fishes of many kinds feed upon mosquito larvæ and destroy large numbers of them. A pond well stocked with sunfish or other species of small fish seldom breeds mosquitoes, except possibly in isolated pools around the edge where the fish cannot go.

Other Insects That Carry Disease Germs. During recent years the general subject of insects as germ carriers has become one of the most important lines of investigation of those interested in conserving health. Among the forms that should be mentioned are the *fleas*. These insects, often found upon rats and other rodents, are now known to be responsible, in a large measure at least, for the bubonic plague. This disease was one of the scourges of ancient times, and even now it is responsible for a great number of deaths in the Old World. Rats become infected, and the fleas that feed upon their blood transmit the germs to human beings. *Body lice* also are at times much feared. These insects are carriers of the germs of typhus fever, the disease that caused so many deaths in Central Europe during the Great War. In the tropics certain species of *flies* carry the germs of sleeping sickness and a number of other dreadful maladies of those regions.

CHAPTER XIV

Zon.

ORGANISMS AND THEIR ENVIRONMENT

INTERRELATIONS OF ANIMALS AND PLANTS

Examples of Interrelations of Animals. In the earlier pages of this book we have shown how animals and plants are, almost without exception, mutually dependent upon each other. 1. Living things depend upon green plants for their organic foods; and, on the other hand, the green plants themselves could not continue to live were it not for the lower plants and animals that break down the complex organic materials into simple compounds. (Page 169.) 2. In the hay culture and in natural bodies of water as well, the organic matter furnishes the food for bacteria. These organisms, together with the simple algæ, form the food supply of the lower protozoans. The higher protozoans and the simpler many-celled animals, which utilize the lower protozoans for food, become the prey of young fishes and minnows, which in turn are the chief food of many larger fishes. The larger fishes are eaten by various higher animals, including man. Throughout this cycle, portions of organic matter are decomposed into simple compounds suitable for the use of green plants. (Page 366.) 3. Among the insects discussed in the pages just preceding, even more striking examples of this general relationship among living things are cited. The control of locusts by their natural enemies, the observations upon the aphids and ladybirds, the relation existing between cabbage butterflies and their parasitic enemies, and the interrelation of parasites with each other are all good illustrations of this general principle. 4. The relationship between the vertebrates and their natural enemies is most remarkable. The control of insects and other pests by birds is one of the clearest examples of the interdependence of living things. (Page 453.)

Food Supply and the Interdependence of Animals and Plants. In all of these examples, interrelationship between living forms is concerned with the food supply. *The food supply of animals, in general, is the most important single factor in determining their abundance and distribution.* Other important influences, however, such as frosts, droughts, excessive rains, and diseases of various types, render the interrelationships of living forms much more complex than they appear in the simple illustrations mentioned above.

The "Balance in Nature." The general interdependence of plants and animals has resulted in a condition referred to as the "balance in nature." The various forms when undisturbed remain in a *state of equilibrium* as a result of the development and adjustments that have taken place through the great period of time during which they have lived upon earth. The specific cases cited above are illustrations of the general principle.

This intricate relationship among living things may be compared to a web or to a net. The breaking of a single strand in a spider's web may affect distantly removed portions of the structure. In much the same manner, the disturbance of the "balance" existing between associated living forms may, and often does, bring about adjustments that are least expected. *The disturbance of this "balance" in nature by civilized man has been the source of untold expense and trouble for the human race.*

The "Balance" as It Existed in America at the Coming of the White Man. When civilized man came into America, he found the various forms of life in a state of equilibrium. The Indians were a product of nature and took their place as one of the natural groups of living things. The birds, the insects, the other animals, and the plants as well, were existing in comparatively stable equilibrium. If locusts, for example, became too numerous, their natural enemies, as well as the failure of their food supply, would bring them back again to their normal numbers. The general principle would apply to birds or other organisms that tended to become excessively abundant. Doubtless adverse weather conditions and diseases disturbed the balance at times; but after such

temporary influences ceased to exist, equilibrium would be established again.

Man's Disturbance of the "Balance in Nature" through Cultivation of the Soil. Just the way in which the white man interfered with the "balance in nature" and thus brought trouble upon himself is most interesting. Some disturbance in the natural order of things in America in the early days was unavoidable. In order to provide themselves with food and the other necessities of

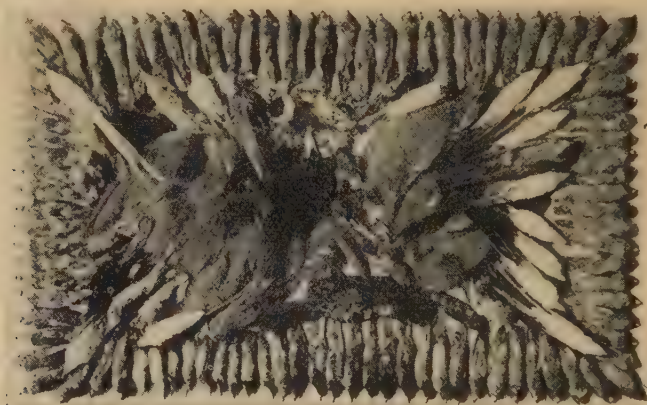


FIG. 210. — BIRD SKINS SUCH AS THESE WERE FORMERLY SOLD IN LARGE NUMBERS FOR THE TRIMMING OF HATS (Photograph furnished by W. T. Hornaday)

life, the settlers had to clear the land, drain the swamps and low areas, and break up the prairie soil. Consequently, the breeding places and feeding grounds of vast numbers of birds and other living creatures were destroyed, and the abundance of the animal life was greatly reduced. On the other hand, the crops that the inhabitants raised provided an unlimited food supply for a large number of insects and other animals.

The Direct Destruction of Wild Life by Man. If the disturbance of the "balance in nature" in this country were due only to the cultivation of the soil, the white man would be blameless. The soil had to be tilled and food produced in order that man

himself might live. Civilized man, however, is far from guiltless. Birds and other animals by the countless millions were killed for food, for the adornment of hats and other articles of clothing, and also for the sport itself. This slaughter was carried on until many species of valuable animals were blotted out of existence.



FIG. 211.—YOUNG EGRETS STARVING IN THE NEST
The parents had been killed for their plumes. (Photograph furnished by W. T. Hornaday)

To-day, however, people have awakened, and a great number of species that were rapidly approaching extermination a few years ago are now by timely laws being saved from extinction. *Surely every citizen should take an active part in the conservation of our wild life.* (Fig. 213.)

The Increase of Destructive Insects during Recent Years.
In America civilized man disturbed the "balance in nature" as it concerns insects in at least three distinct ways. 1. He destroyed vast number of birds and other living creatures that held in check the vegetable-feeding types. 2. He furnished these destructive forms with a plentiful food supply. 3. He introduced large numbers of new species into this country from foreign lands. Many of these, at least, are not controlled by natural enemies. As a consequence, such insects do a great deal of harm. Civilized man in America has *destroyed his best friends* and has *aided his worst*

enemies. It is not surprising that such pests cost the country hundreds of millions of dollars annually.

Instances in Which Man Has Disturbed the "Balance in Nature." Many specific cases could be cited where man has

caused much trouble by interfering with animal life as it exists in nature. Brief statements of a few such examples will be of value.

The *potato beetle* is a native of the semi-arid regions just east of the Rocky Mountains. There it used to feed upon certain wild plants of the family to which the Irish potato belongs. At the time the early settlers entered this territory the beetles and the food plants were apparently in a state of equilibrium. The Irish potato was introduced into the Rocky Mountain region about 1850 and soon became the chief source of food for this insect. As its food supply became unlimited, the insect increased rapidly and was soon a serious pest. In a comparatively few years it spread eastward to the Mississippi River and finally, in 1874, reached the Atlantic Ocean.

Another interesting illustration of this same point is found in the introduction into California of the *fluted scale*, an insect that at one time threatened to destroy the orange groves of this state. An investiga-



FIG. 212.—THE FLUTED SCALE ATTACKED BY THE AUSTRALIAN LADYBIRD BEETLE

Lower right-hand corner. A beetle that has just issued from its pupal case. (From *American Insects* by Vernon Kellogg, published by Henry Holt and Company. By permission)

tion indicated that this pest had been imported from Australia on certain trees that were brought into California in 1868. It was discovered, also, that in Australia the fluted scale caused no

great damage, due to the presence of a natural enemy, a small ladybird beetle, that preyed upon the pest and held it in check. These beetles were accordingly brought into California and released in the infested orange groves. In this way the "balance" between the ladybird and the fluted scale was reestablished and the danger from this pest was removed.

In Australia predacious animals, such as are abundant in many other countries, are not found. Consequently, about 1850, when



FIG. 213. — RESULT OF BIRD PROTECTION

The photograph of these wild Canada geese was taken from a window in Jack Miner's house, Kingsville, Ontario. Mr. Miner says, "It isn't the birds that are wild, it's the human race." This lover of birds "has thrown a handful of corn instead of a thimbleful of shot" with the result shown in the cut.

rabbits were introduced, there were too few natural enemies to control them. With a plentiful food supply and with other conditions suitable for multiplication, the rabbits increased enormously. In the course of a relatively few years the country became literally overrun with these pests. At present a constant war upon them must be waged in order to protect the crops against destruction. Surely it is not a trivial matter for man to disturb the "balance in nature."

A remarkable case is found in the *Kaibab Plateau* in Arizona. (See *Nature Magazine*, March, 1925.) A few years ago, pumas, coyotes, wildcats, and wolves were abundant in this region. They preyed upon the deer and effectively held them in check. Hunters were encouraged to enter the Kaibab Forest Reserve and destroy the predatory animals. Up to 1923, 672 pumas, 3,000 coyotes, 120 wildcats, and 11 wolves were reported killed. As a result, the deer increased rapidly, and in 1924 they were said to be so numerous that the natural food supply was entirely inadequate to support them. In many places the bushes and young undergrowth upon which the deer feed in this dry region were annihilated, and the animals were facing starvation. The situation is so serious that the Forest Service is using every effort to decrease the number of deer in this isolated district by distributing the animals to other localities where food is more plentiful. Advertisements now state (1925) that deer may be had for propagation purposes at thirty-five dollars per head, a price that merely pays the expense of capture and crating the animals.

ORGANISMS IN RELATION TO THE PHYSICAL AND CHEMICAL CONDITIONS ABOUT THEM

Behavior of Plants and Animals. Plants and animals generally are well adapted to live in their special environments. Frequently they behave in a most remarkable manner with reference to the influences and conditions about them. Green leaves very often are arranged upon plants in a way that fully exposes them to the direct rays of the sun. Many flowers close at night and open during the day, while others open only at night when nocturnal insects are active. The shoots of seedlings grow upward into the air where light can strike the leaves, and the roots extend downward into the soil where moisture and other necessary substances may be obtained. Many night-flying insects gather about electric street lights or enter well-lighted rooms through open windows. Bees and ants behave in the most complex manner in their activities about their hives and nests. The behavior of birds and other vertebrates in

building nests and in rearing the young, and the methods they employ for self-preservation often seem almost human. Many of these activities are highly valuable to the species concerned. In fact, the movements and adjustments of many lower forms are so striking, and the habits of numerous members of the higher groups are so remarkable, that people interested in plants and animals often are misled concerning the real nature of their behavior.

Incorrect Ideas as to the Cause of Plant and Animal Activities. Very often the remarkable activities referred to above are interpreted incorrectly as the result of *conscious choice* on the part of the plant or animal concerned. Many of the movements and habits that are of value to such organisms are believed to be of the same general nature as the useful human activities in which intelligence and judgment are definitely involved. False interpretations of this sort are met with very frequently, especially in popular articles upon plants and animals. A statement of a few of these will be helpful.



FIG. 214.—BRANCH OF PURPLE BEECH SHOWING HOW THE LEAVES ARE EXPOSED TO THE LIGHT
(Original photograph)

The leaves of green plants that turn towards the source of light *are supposed* to do so because the plant, in some *conscious* way, *wishes* or *wills* for such movement to take place, just as a person intentionally arranges his house plants so that they may be fully exposed to the direct rays of the sun. Certain flowers likewise *are said* to close at night or in the storm because they *desire* to do so in order to sleep or to protect their pollen from being washed away. Others *are believed* to open their petals at night because they *wish*

to be visited by suitable insects to insure pollination. According to the same point of view, shoots of seedlings grow upward and the roots downward, because of some *conscious purpose* existing within the plant; also, moths fly toward lights because they have a *motive*



FIG. 215.—ROSETTE OF LEAVES OF A YOUNG MULLEIN PLANT (Original photograph)

in so doing; and the behavior of birds, bees, and ants is directed by the same types of higher mental processes as function in man. In fact, these last-named forms, in their complex nest-building and in their other activities, are sometimes accredited with powers at least akin to those of human architects and hunters. In brief, there has been and still is a widespread tendency to interpret the behavior of plants and lower animals just as if these organisms were gov-

erned by human intelligence and human emotions. *Such conclusions are far from the truth and certainly are not justified by experiment.*

Cause of the Behavior of Lower Organisms. Of recent years, experiments have proved conclusively that many of the movements and activities of the plants and the lower animals are the direct results of simple external *stimuli*, such as light, gravity, and chemicals. Even the complex behavior of many of the higher forms, such as birds and mammals, is closely connected with these same factors in the environment. Living substance, in general, is sensitive to such stimuli, but plants and lower animals in no sense consciously originate the responses to them. In other words, these organisms behave much like machines. Their acts are not the result of some definite purpose existing within the plant or animal and cannot be attributed to *mind*, as this term is ordinarily used in reference to human beings.

In the higher groups of animals the behavior becomes much more

complicated, but stimuli of the general types mentioned above also play an important part. The extraordinary nest-building habits of some birds, for example, are now believed to be connected with temperature changes and other physical and chemical influences. The same is true, in general, with reference to the migrations of birds, although in these cases temperature may not be the most important factor. It should be noted in this connection, however, that, in the higher groups of vertebrates, the simpler manifestations

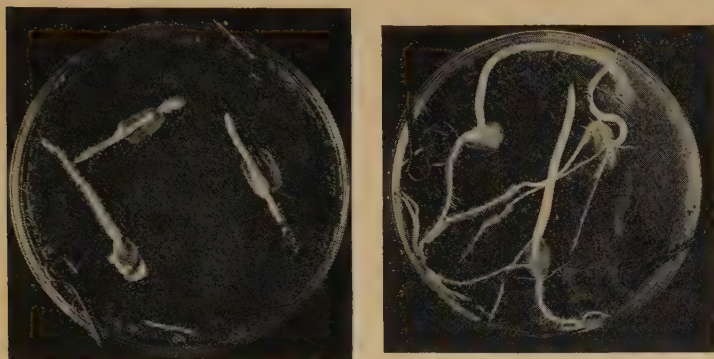


FIG. 216. — (From Stevens' *Introduction to Botany*)

Seedlings of Indian corn grown in sawdust in a Petri dish while revolving by clockworks one revolution per hour. The axis of revolution is horizontal, the plane of the dish vertical. Gravity as a directive agent is eliminated, and roots and shoots grow out in the direction in which they happen to be pointed.

Seedlings of Indian corn grown in sawdust in a Petri dish which was kept stationary in a vertical plane in the position shown in the figure. Gravity is acting as a directive agent, and the roots find and take the downward and the shoots the upward direction, irrespective of the directions toward which they were originally pointing.

of the mental processes which we associate with man's behavior begin to play a more or less important part.

Physical and Chemical Stimuli. Among the more important physical and chemical stimuli that commonly affect organisms are gravity, light, moisture, mechanical contact, temperature, and chemical substances of various sorts. The growth and other movements

of plants and often the habits and general behavior of the lower animals are definitely modified as a result of these stimuli.

The *effect of gravity*, or *geotropism*,¹ causes the shoots of seedlings to grow upward and the first roots downward. Likewise, green plants that have been blown down or have been bent over in other ways often become practically erect again because of growth responses to this stimulus. The positions of the fruiting bodies of many fungi, mushrooms for example, are also mainly determined by geotropism. In some cases, gravity causes growth to take place in other directions than those indicated above. In general, it may be said that the type of development depends upon the specific manner in which the plant responds rather than upon the direction from which the stimulus acts. Geotropism influences the growth of plants throughout a large portion of the vegetable kingdom.

The *effect of light*, or *phototropism*, like geotropism, often brings about marked changes in the positions of leaves and stems of green plants; it also greatly modifies the behavior of many lower animals. The leaves of a geranium that stands before the window and receives the light from one side only, turn in such a way as to be fully exposed to the rays. Seedlings of oats and of many other plants, when subjected to light rays even for a very short time, speedily bend toward the source of the stimulus. Light also has a marked effect upon the opening and closing of flowers and upon the positions of the clusters. The movements of the sunflower head that keep it facing the sun throughout the day is an excellent example of the effect of light in modifying the position of a part of a plant.

The *effect of moisture*, or *hydrotropism*, at times becomes a strong directive force in determining the nature of root systems of green plants. The hyphæ of some fungi also respond to this stimulus. A remarkable example of hydrotropism is the tendency of roots to grow into tile drains, wells, and cisterns. In one case that came under the author's observation, the walls of a large well

¹ In the study of animal behavior, the terms geotaxis and phototaxis are used to refer to the effects of gravity and light respectively. Corresponding terms are used with reference to the other stimuli.

for a number of feet down were covered, to a thickness of almost a foot in places, by the fibrous roots of some nearby Carolina poplars. The drains near which elms and willows are growing often become so nearly filled with roots that the tile must be dug up in order that the obstructions may be removed.

The *effect of mechanical contact*, or *thigmotropism*, is another means by which very interesting modifications in certain plant structures are brought about. Probably the most notable and also the most easily observed examples are found in the tendrils of climbing vines. These structures which, in the grape, arise at the nodes on the opposite side of the stem from the leaves, are at first practically straight filaments several inches in length. The slightly curved tips extend well out beyond the developing leaves. The young tendril, as it reaches full growth, begins a slow but regular movement that swings the end around in all directions. Sooner or later, the tip is likely to rub against some solid object, such as a wire or other suitable means of support. This mechanical contact initiates a growth movement that causes the end of the tendril to wrap securely about the solid object; the central portion then coils into spirals and thus draws the stem closer to the support. Finally the whole structure grows hard and rigid. By this series of responses in the numerous tendrils, the vine becomes firmly attached to the object over which it is climbing.

A number of other stimuli also are very influential in determining the activities of lower organisms. The cases briefly discussed above were selected because of the ease by which they may be observed. Temperature and various chemical substances often are important influences, but since it is difficult to study these stimuli in an elementary way, they are omitted in this discussion.

The Utility of Responses. Many of the responses discussed above are of great value to the organism. The upward growth of the leaves into the light and the downward growth of the roots into the soil, where the required food substances occur, are necessary for the development of the plant; the adjustments of the leaves and stems through phototropism are beneficial from the standpoint of photosynthesis; the effect of water upon the direction of root growth,

at least in relatively dry soils, is also of value; and the complex responses of tendrils to contact enable the slender vine to reach up and spread its leaves in the open sunlight. The obvious utility of such activities is largely responsible for the *mistaken belief* that lower organisms exercise more or less conscious choice in the matter of their behavior.

On the other hand, some responses are detrimental to the organisms concerned. When night-flying insects collect about electric lights they are destroyed in large numbers, and the same is true of various moths and beetles that enter well-lighted rooms during summer evenings. Certainly no conscious or useful *purpose* can be involved in such acts. The May beetle, for example, often collides again and again with the glass globe until it falls exhausted. The effect of the light coming from one point seems to set in operation a mechanism which causes the insect to fly automatically towards the source. The shock of striking the globe may drive the beetle from the light for some distance; but the insect is likely to respond to the stimulus again and continue to hover about the lamp. Birds in their migrations on dark, stormy nights are also attracted by strong lights. Sometimes they are killed in large numbers by striking the glass windows of lighthouses. With the birds, however, it is likely that the responses are much more complex than those of the night-flying insects.

On the whole, evidence justifies the conclusion that many actions and movements of lower organisms consist mainly in unconscious, mechanical responses to definite physical and chemical stimuli. The peculiar mechanism of their bodies compels the various forms to act as they do. Conscious purpose plays little or no part in the simple behavior of such organisms.

Variations in the Complexity of the Behavior of Organisms. As we proceed up the scale, we find, in general, that the activities and mental processes of organisms form an unbroken series of increasing complexity. With the plants, the movements and types of growth consist in automatic responses to stimuli. In the lower groups of animals, the reactions become more and more involved and form the basis for the complex actions of the higher

groups; but even among the fishes, frogs, reptiles, and birds, external stimuli play a more or less important rôle. With the higher vertebrates, genuine mental activities, such as we associate with man, begin to appear. In such mammals as the dog and the horse, there is definite evidence of intelligent action and sometimes indications of the simpler forms of thinking.

The importance of automatic responses in the behavior of the higher vertebrate is very difficult to determine. It is also impossible at present to say just how far down in the groups of lower animals intelligent action of the simplest type exists. Some complicated activities which, on first sight, seem to be governed by a high degree of intelligence, are now known to be the result of chemical and physical stimuli of various sorts. In a like manner, much of the behavior that appears to involve *thinking power* on the part of the animal consists in instinctive responses or in automatic reactions to various stimuli.

As a result of the overlapping of the various mental processes, it is difficult to group all of the types of behavior of higher animals in a satisfactory manner. For convenience, however, we shall discuss this phase of the subject under two heads: *instinctive action*, and *intelligent action*.

Instinctive Acts. Instincts may be defined as, *inherited* tendencies to perform a specific action in response to definite stimuli or situations. In this type of behavior, all of the normal members of a species perform the acts in essentially the same manner. There appears to be little or no improvement in the method as the result of practice and repetition. The animal does not learn by doing; it is born with the ability to perform the act. The young robin, for example, that has never built a nest selects essentially the same kinds of materials and constructs the same type of structure as others of the species.

Utility of Instinctive Acts. Instinctive acts vary greatly in their utility to the animals concerned. For example, instincts that have to do with the care of the young are absolutely essential to the life of the species, while others have no such marked utility. The cat, although it instinctively preys upon living animals, often pro-

cures its foods in other ways. Some instincts are of little or no value to the animals under their present conditions of life. Such is the case with the fluttering of the dove when it flies from its nest, or the clucking of the sitting hen when she leaves her eggs to search for food.

Cases Illustrating Instincts. A few definite examples involving instincts will serve to illustrate the extreme complexity of this type of behavior in animals.

The *fur seal* breeds in the far north upon the Pribilof Islands in the Bering Sea. In the fall the animals travel southward in the open seas down to a point off the coast of southern California. The following spring they again appear at their breeding grounds upon a date that is said to vary remarkably little from year to year. Throughout this extensive migration covering thousands of miles, the seals do not touch land. The instinct that directs this great herd through the vast stretches of open sea and eventually brings the animals back to their summer homes, essentially at the same time each spring, is indeed marvelous.

The behavior of the *Columbia River salmon*, in its migrations to and from the spawning grounds in the shallow streams sometimes a thousand miles from the sea, is even more remarkable than that of the seals. This valuable fish lives in the deep sea during a large part of its life. When the spawning season approaches, the salmon enter the mouth of the Columbia in early spring and proceed up stream until they reach the headwaters. In the course of this journey, which requires months, the fishes must frequently pass rapids and even waterfalls of considerable height. During this movement they take no food. In the autumn, when the spawning grounds are reached, the eggs are deposited and fertilized, and the parents drift back down the stream and finally die. No mature salmon, after spawning, ever reaches the ocean alive. The directive force that guides these hordes of fishes upon their long journey certainly is sufficient to excite wonder. We say it is instinct, but, fundamentally, little is known concerning the nature of such behavior.

Examples of instincts, many of which are just as striking as those cited above, are extremely abundant and may be observed by any-

one. The migrations of birds to and from their breeding ranges, and their activities in nest-building and in the care of the young; the remarkable behavior of a colony of honey bees or of ants; the food habits of the garden toad; the ways in which rabbits and squirrels escape their enemies; and even the activities of the lowly fishworms and the crayfishes — all are highly interesting. The student, however, will have to rely upon his own observations and upon reference work for information in these cases.

Intelligent Acts. For our present purpose, intelligent acts may be defined as those types of behavior that are acquired through *practice* or *training*. Unlike the instincts, such activities are not innate. The ability to learn is inherited, but the method by which the act is performed is acquired. An animal is said to be intelligent when it is capable of learning through experience or training.

Lower Types of Intelligence. Behavior that involves a low degree of intelligence on the part of the animal is quite common, especially among the higher groups of vertebrates. As far down as the fishes there is some evidence of such actions. In fact, it is difficult to state with certainty just how low in the scale of animal life this faculty in its simplest form first manifests itself. Beginning with the birds, however, and extending throughout the group of mammals, the behavior becomes more and more influenced by intelligent action, although instinct is still definitely involved, even with man himself. For example, a young horse may become frightened at the ringing of a fire-bell. This reaction probably is largely instinctive. But after some training, the animal may trot out of the stall at the same sound, and take his position before the hose wagon, ready for immediate service. This behavior indicates intelligence. The horse was *taught* to act in this manner. Again, the young bird-dog often has an instinctive inclination to eat the bird shot by the hunter, but intelligence manifests itself when the animal is trained to carry the dead bird to his master.

Higher Types of Intelligence. **Judgment.** Judgment, as we shall consider it, is the type of mental activity that involves *comparison* of ideas and *conscious choice* of the means to be used in the accomplishment of some desired end. Past experiences are

brought to bear upon the problem at hand, and methods are devised for its solution. Abstract thinking is the result.

Behavior due to judgment is not necessarily complicated. In fact, such acts are often more easily explained than some that are typically instinctive. Bird and other animal migrations which seem to be mainly due to instinct are among the most complicated activities in all the field of animal behavior. Acts involving the lower forms of intelligence often are not difficult to distinguish from judgment, if one takes into consideration the origin of the two types of behavior.

When a dog learns to open the latch of a gate, the mental processes involved are very different from those employed by a boy engaged in the same activity. The results are similar; but the dog learns to open the latch by repetition of some haphazard act, such as clawing at the lock, while the boy, who has studied the mechanism of the lock, profits by his past experiences and consciously decides upon a course of action. The first case involves a simple form of intelligence, and the second, judgment.

A heavy hog was observed to bump against a small apple tree with sufficient force to shake some apples to the ground. The animal then ate the fallen fruit and again jarred the tree. To all appearances, judgment was involved, for the hog apparently had *devised* a method by which to get the fruit. However, another explanation is more satisfactory. The tree grew near a hog wallow, and the animal, upon coming from the mud, probably had rubbed against it. As a result of this instinctive act, apples had fallen to the ground. The process, doubtless, was repeated again and again until the animal had *learned* how to shake the tree. Thus the act was due to a simple form of intelligence although it seemed to involve judgment.

Human Behavior. Instinctive acts are very important in the behavior of young children. As the child develops, however, the lower types of intelligence soon come to play the more prominent rôle. Still later, judgment, or the power of abstract thinking, begins to assert itself. Nevertheless, acts involving the simple forms of intelligence continue to be determining factors in behavior throughout life. With the lower groups of feeble-minded, the men-

tal processes are permanently of a very low type. In such cases judgment never appears.

On the whole, it is doubtful whether judgment occurs to any great extent below man. There are, perhaps, scattered among the higher groups of mammals, individuals that possess this capacity to some extent. With the vast majority of vertebrates below man, however, the behavior can better be accounted for as due to the lower forms of intelligence and to instinct, rather than to judgment.

CHAPTER XV

VERTEBRATES

GENERAL NATURE

Those forms belonging to the highest branch of the animal kingdom are referred to in general as the *chordates*. The majority of these — in fact, all that are of importance to man — are included in a large group known as the *vertebrates*.

Characters of the Vertebrates. The vertebrates include all of those animals that have *backbones* and *internal skeletons*. Although the backbone varies somewhat in the various classes of vertebrates, on the whole this structure is quite uniform throughout the entire

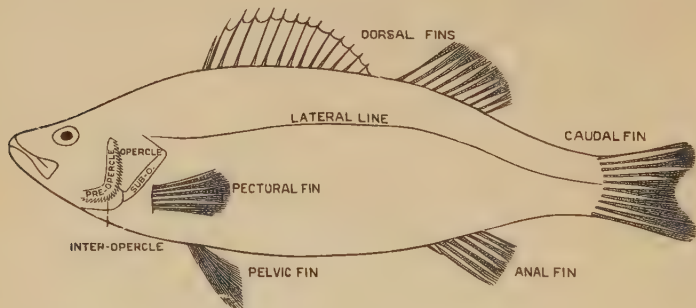


FIG. 217. — EXTERNAL FEATURES OF A PERCH (From Colton's *Zoölogy*, page 154)

group. In some of the lower fishes the skeleton is composed of cartilage, but in all other vertebrates it is composed of hard and resistant bones.

The *backbone*, or *vertebral column*, as it is sometimes called, consists of a series of very irregular bones, the *vertebræ*, arranged end to end. The *vertebræ* are held in place by ligaments which allow more or less freedom of movement. This bony column extends

from the skull through the dorsal region of the body to the posterior end, and in many cases it forms the framework for the tail. The vertebral column is the support or axis about which the body of the higher animal is built.

Classes of Vertebrates. There are five classes, or subdivisions, of the great group of vertebrates: *fishes*, *amphibians*, *reptiles*, *birds*, and *mammals*. These classes differ so widely in their general character and are so diverse in habits that a brief description of each is advisable.

Fishes are water-inhabiting vertebrates that breathe by means of gills and swim by the use of fins supported upon a bony or a cartilaginous framework. Their eggs are deposited in the water and are fertilized outside the body. The skin of fishes is well supplied with mucous glands that give rise to the slimy coating on their bodies. Many fishes are covered with scales, but in some this characteristic is lacking.

Amphibians are those animals, such as toads, frogs, and salamanders, that have a very definite metamorphosis, suggestive of

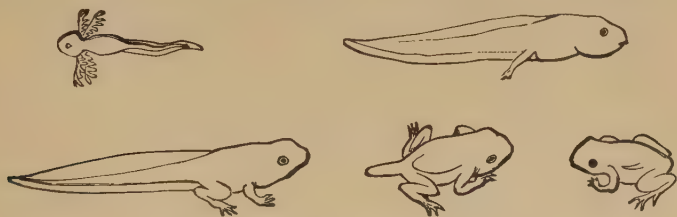


FIG. 218. — DEVELOPMENT OF A TOAD

(From Colton's *Zoölogy*, page 189)

the development of some insects. The young, known as tadpoles, are similar to fishes in their habits. They breathe by means of gills and feed much in the same way as fishes. They also resemble the fishes in their form and in their method of locomotion, but the bony or cartilaginous fins are lacking. From this stage, the tadpole changes into an air-breathing adult. Like the fish, the amphibians reproduce by means of eggs that are deposited in water. The skins of the animals belonging to this group are generally smooth and

destitute of scales; although in some, as the garden toad, they are quite rough and warty.

The *reptiles*, which include a number of very different types of animals, such as snakes, lizards, turtles, and alligators, do not pass through any definite metamorphosis. The young are either born alive, as is true with certain snakes, or they are hatched from eggs that are generally deposited in suitable locations in or upon the surface of the earth, as is the case with turtles. The young reptiles at the time of hatching generally resemble the adults quite closely. Although many of this group live in and about the water and often swim well, they breathe by means of lungs. (Fig. 224-229.)

The *birds* are closely related to the reptiles in structure, but, unlike this latter group, they are more uniform in character. The covering of the body consists of feathers. These differ greatly in size and structure and vary from the large plumes of the ostrich, and the strong quills of the goose or eagle, to the small downy feathers upon the young chick. The ability of sustained flight is quite typical of birds throughout the group, although some lack this power. For example, the penguins have only rudimentary wings, and the domestic fowl has practically lost the ability to fly well through long domestication. Birds always reproduce by means of eggs, which generally are incubated in the nest by the adults. The parents feed and protect the young for a time after hatching, in marked contrast to the reptiles and other lower groups of vertebrates which in a large majority of cases allow their young to shift for themselves.

The *mammals* include the so-called four-footed animals and man. The bodies of these animals are covered more or less completely with hair, varying in texture from the coarse bristles of the hog to the extremely fine fur of the mole. A few are comparatively or entirely naked, as the elephant and hippopotamus. Mammals, with a few exceptions, produce living young, which are nourished by milk produced by the mother. In the kangaroo and opossum, the young are born in a very immature condition and are reared for a considerable time in a special pouch of the mother.

Most mammals are land-inhabiting forms, but some, as the

whales, are adapted for life in the water. There are also a large number of aquatic types, which are expert swimmers and feed upon fish. All mammals, however, whether they frequent the water or not, breathe by means of lungs in all stages of development after birth. Those that swim beneath the water must come to the surface for air from time to time.

Body Temperature of Vertebrates. Vertebrates are of two general types with respect to the body temperature. Fishes, amphibians, and reptiles have a *variable body temperature*; that is, it varies with that of the surroundings. Birds and mammals have a *constant body temperature*, which is only slightly affected, if at all, by the temperature of the environment. These facts are important in determining the distribution and habits of animals. Birds and mammals with but few exceptions remain active during cold weather, while the reptiles and amphibians generally lie dormant at this season. Fishes, in certain cases, are quite active during the winter, because of the relatively high temperature of the water in which they are found.

Digestion in Vertebrates.

The resemblance between the digestive systems of the vertebrates is surprising, in view of the diversity of form and habits

in these animals. As has been stated before, the fundamental digestive processes are the same in all living things, and consequently, similarity in the production of the digestive fluids and in their action

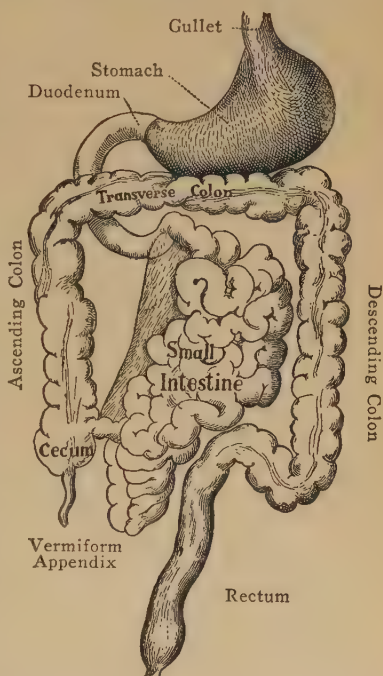


FIG. 219. — STOMACH AND INTESTINES OF MAN, A VERTEBRATE

(From Colton's *Zoölogy*, page 283)

is to be expected. It is very significant, however, that the corresponding organs of the various digestive tracts differ only in detail, and that the entire systems are built upon essentially the same plan throughout all the classes. This likeness in structure points to one definite conclusion: *vertebrates*, diverse as they seem at first sight, *are genetically related to one another*. This conclusion is not only indicated by a comparison of the digestive organs of the vertebrates, but it is also verified in a remarkable way by a study of the other systems.

Circulation in Vertebrates. The circulatory systems of the vertebrates are much more highly developed than those of the simpler types of animals. They consist of a definitely chambered heart and extensive blood vessels. Even in the lower classes, the circulation closely resembles that in man: the blood is pumped to all parts of the body through the arteries and, after passing through the capillaries, returns to the heart by way of the veins. (Chap. X.) The steps in the development from the comparatively simple heart of the fish to the complex heart of man are very interesting.

The heart of the *fish* is the simplest type found among the vertebrates. The organ proper consists of *two chambers*, an auricle and a ventricle. Two enlargements in the blood vessels adjoining the heart are looked upon by some authorities as parts of this organ. These structures, however, become reduced and practically disappear in the higher classes. The blood passes through the auricle and enters the ventricle. From this cavity it is forced to the gills, through the various organs of the body, and back to the heart in one continuous round. Thus there is said to be a *single circulation* in this animal.

The *amphibian* heart is somewhat more complex than that of the fish. The single auricle contains an incomplete partition that tends to keep the blood from the lungs separated from that coming from the other parts of the body. The blood from the right and the left portions of the auricle passes into the ventricle, which forces it into the arteries. The partition in the auricle tends to cause the venous blood, which is deficient in oxygen, to pass to the lungs and the skin,

where it is aërated. On the other hand, the arterial blood, which is well supplied with oxygen, is mainly guided to the other parts of the body.

With the *lower reptiles* the partition between the auricles is complete, and the ventricle also is partially divided. Here, then, is a *three-chambered heart* in place of the two-chambered one of the fishes and the amphibians. In the alligator, which is one of the *higher reptiles*, there is a *four-chambered heart*, for the partition in the ventricle is complete. Even here, however, the blood of the two ventricles may fuse to some extent after leaving the heart.

In the typical four-chambered heart, such as is found in *birds* and *mammals*, the right side pumps the blood through the lungs, where it takes in oxygen, and then the left side receives the aërated blood from the lungs and forces it to all parts of the body. The blood in one complete circulation passes through the heart *twice*. Thus, in these higher forms, there is said to be a *double circulation*.

Respiratory Systems of Vertebrates. As has been stated before, the fundamental act of respiration — that is, the oxidation of the food in the living tissues — is the same in all organisms; but the mechanisms by which oxygen is obtained for this process are of especial interest in the various classes of vertebrates.

In the *fishes* the *gills* are the special organs adapted for the purpose of supplying the blood with oxygen. These organs consist of delicate membranous structures supported upon bony arches, which may be seen on either side in the back of a fish's mouth. The water containing dissolved oxygen is drawn into the mouth and forced out through the gill openings, which are on the sides and posterior to the fish's head. In this way the water comes into contact with the delicate gill membranes. By diffusion, the blood in the membranes takes in oxygen and gives off carbon dioxide to the water. The air bladder, which is a membranous sack situated in the dorsal portion of the body-cavity and concerned chiefly in the control of the specific gravity of the animal, probably plays a part in respiration, at least in some cases.

In the young of *amphibians*, oxygen is obtained by means of gills,

as in the case of fishes. The adults, however, have simple lungs, which are sack-like structures filled with air. The blood flows through the numerous capillaries of the lung walls, and the exchanges between the blood and the air take place in much the same way as in man, as discussed in Chapter X. In the amphibians that have moist skin, the whole surface of the body aids in supplying the blood with oxygen and in ridding it of carbon dioxide. Amphibians do not breathe like man and the other higher vertebrates. In the frog, for example, the lower walls of the mouth act somewhat like a bellows in forcing the air through openings at the back of the mouth cavity into the sack-like lungs.

The respiratory organs of *reptiles*, *birds*, and *lower mammals*, which all breathe by means of well-developed lungs, are so similar to those of man that additional discussion is not necessary. It may be said that in the birds air spaces occur in various parts of the body that aid in the general respiratory process.

Excretory Systems of Vertebrates. The excretion of waste substances is one of the important life processes of all animals. The breaking down of the living substance and of the complex organic foods produces wastes that must be eliminated, if life is to continue. Carbon dioxide and nitrogenous wastes are the most important substances, from the standpoint of excretion, that must be disposed of. As was pointed out above, the carbon dioxide is given off at the same time as the oxygen is received by the blood from the lungs, gills, or skin.

The nitrogenous wastes are disposed of through a special set of organs known as the *urinary system*. This consists of the *kidneys*, which remove the wastes from the blood, *tubes* that carry the excretions from the kidneys, and the *urinary bladder*, which serves as a reservoir for the substances until they are passed out of the body. In the birds there is no bladder, and the secretion of the kidneys flows directly into the lower portion of the digestive tract and passes out with the feces. In their fundamental nature, the kidneys are rather uniform throughout the entire group and call for no special discussion here.

Nervous Systems of Vertebrates. The nervous systems are

much more specialized in the vertebrates than in the lower groups of animals already studied. Here for the first time is to be found a definitely formed *brain*, consisting of several well developed portions and situated in a bony cavity known as the skull. The brain develops as a specialized portion of the *spinal cord*, which extends back through the opening in the vertebral column. From this cord, as well as from the brain itself, numerous *nerves* radiate to the various organs of the body.

A discussion of the variations occurring in the nervous systems of the different classes of vertebrates is not necessary for our present purposes. It is sufficient to note that there is a decided increase in the size and complexity of the brain from the fishes through the amphibians, reptiles, birds, and lower mammals, up to man, whose brain is by far the largest, compared to his size, and the most complex.

Size of Brain and Intelligence. The changes in size and complexity of the brain from the lower classes to the higher are coincident, in the main, with the increase in the general intelligence or power to learn. As has been said, the lower classes are controlled almost entirely by instincts or inherited ways of doing things; while the higher forms, notably the mammals, although they too are governed chiefly by instincts, are much more capable of learning through experience. Man's intellectual capacity is far above that of the lower mammals.

Reproduction in the Vertebrates. Like the other life processes, fertilization, which underlies sexual reproduction, is essentially the same in all living things. In the various classes of vertebrates the egg cells and the sperms are all quite similar and are produced by special sex organs. Any differences that occur are in minor details rather than in fundamental characters.

Vertebrate Embryos. The development of the embryos after the union of the sex cells is remarkably uniform in character throughout the groups. In the lower and also the higher classes, the young in the early stages are almost identical in structure and in their general character. At this period the embryos of fishes, amphibians, reptiles, birds, and mammals, including man, are practically indis-

tinguishable from one another. However, at successively later stages, the fish embryo ceases to advance and becomes the typical young of this class, the amphibian develops amphibian characteristics, the reptile, too, takes on the definite reptilian form, the bird becomes bird-like, and the lower mammal becomes more and more complex until it, likewise, exhibits the definite mammalian charac-

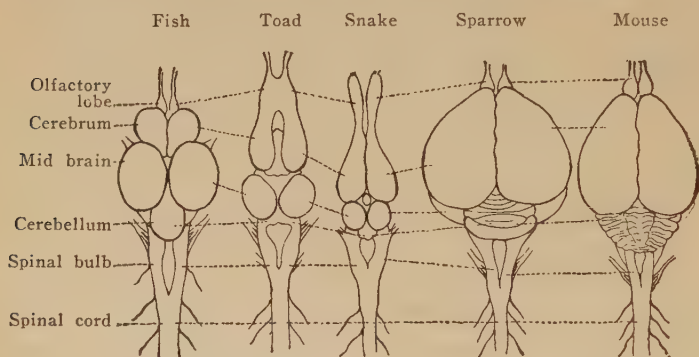


FIG. 220. — DIAGRAM SHOWING THE COMPARATIVE INCREASE IN THE SIZE OF THE CEREBRUM (the largest portion of the brain of higher animals) THROUGH THE FISHES TO THE MAMMALS

(From Colton's *Zoölogy*, page 285, taken from Kellogg's *Zoölogy*)

ters. The human embryo, after passing through the early embryonic stages of the lower vertebrates, continues to develop and finally takes on the human form.

These facts do not mean that the human embryo is at one time a fish, then an amphibian, then a reptile, and so on. They indicate that, in general, the *human embryo recapitulates (repeats) the early stages through which the embryo of these other animals pass before they develop the special structures that distinguish them as fishes, amphibians, reptiles, or lower mammals, as the case may be.*

Production of Young. Some vertebrates produce living young and others deposit eggs; the former are said to be *viviparous*, the latter *oviparous*. Mammals with few exceptions are viviparous,

the other classes are oviparous. In a few reptiles the eggs hatch within the body of the mother, as with certain snakes, and in others they are deposited with the young practically developed within the shell, and hatch later.

Eggs of Vertebrates.¹ Eggs of vertebrates differ much in size and character. Those of mammals are minute and contain only a small amount of stored food. Those of fishes and frogs are much larger and are generally surrounded by mucilaginous layers, which swell up in the water and make the eggs quite conspicuous. They contain sufficient food to enable the embryos to develop until they can get nutriment for themselves. The eggs of birds and reptiles are very large and contain a great deal of stored food which is used by the embryo during development.

The Hen's Egg. The hen's egg is a good example of the type in which much food is stored. The egg cell really consists of the entire food-gorged yolk. The nucleus and most of the protoplasm are found within the lighter colored *germinal spot* or *disk* which may be seen on the surface of the yolk. A thin layer of protoplasm, continuous with that of the germinal spot, separates the yellow food mass within this cell from the albumen or "white" of the egg.

The eggs of some birds contain so much food that the young are nearly able to care for themselves when they are hatched. This is true of the bobwhite. In many other cases the development does not go so far before hatching, and the young are cared for in the nests by the parent birds for a considerable time.

The Food Supply of the Embryos of Mammals. It has been stated that the egg cells of mammals contain but little food, only enough to start the development of the embryo. A very large portion of the nourishment, then, must be furnished by the mother during the gestation period. An understanding of the process by which the young mammal is nourished before birth is very important. It takes place about as follows.

Circulation in the Mammalian Embryo. Very early in the

¹ For the sake of simplicity we are using the term egg to include the egg-cell as well as the structures commonly referred to as eggs.

development of the mammalian embryo, the heart and much of the circulatory system start to function, and a definite circulation of blood supplies all parts of the embryonic body with food and oxygen and also removes the waste materials. The blood of the mother supplies that of the embryo with nourishment and oxygen and likewise carries off the waste materials. This exchange is made possible through an organ of the embryo known as the *placenta*, which lies in intimate contact with the walls of the *uterus* or *womb* of the mother. The blood of the embryo circulates through the placenta, thus coming very near the capillaries of the mother's body.

The exchange of waste materials, food, and oxygen are accomplished through diffusion; in no sense does the mother's blood mingle with that of the embryo (fetus). *The two circulatory systems are entirely separate.* In fact, with the exception of these intimate food relations and the protection afforded the young, the embryo of the mammal develops, after fertilization, about as independently from the mother as the chick within the hen's egg.

Influence of Mother upon the Offspring. It should be clearly understood, however, that any poison or other substance in the mother's blood may pass into that of the young animal and influence its physical well-being. Poor nourishment or any other condition that affects the health of the mother also may definitely injure the offspring.

These facts are easily understood when we recall how sensitive to injurious influences the young of any plant or animal is during its early stages of development. The pig that is stunted from lack of food during the first few weeks of its life shows the effect almost indefinitely. Likewise every gardener knows that seedlings that have been injured by the cold or an excess of water seldom, if ever, produce as well as those that have developed under better conditions. How much more sensitive, then, must the embryonic animal be whose tissues and organs are in the very early processes of formation!

ECONOMIC VALUE OF VERTEBRATES¹

Importance of Products from the Vertebrates. The vertebrates furnish practically all of the animal food used by man. Only a relatively small amount is supplied by the other groups of animals. Notable among these are crustaceans, such as lobsters and crabs, and mollusks, such as oysters and clams.

The classes of vertebrates most important as sources of food are the mammals, birds, and fishes. Among the amphibians frogs are used to a considerable extent, and among the reptiles turtles are sometimes eaten. A few reptilian eggs are also utilized. The foods consist of meat, milk, eggs, and some other products of less importance. A large number of useful materials, such as leather and furs, are also furnished. In fact, so apparent is the importance of vertebrates as a source of food, clothing materials, and other products, that a mere mention of these facts is sufficient.

Vertebrate Pests. Certain species of insects and related forms are by all means the most important pests; but some vertebrates, such as the small gnawing animals known as *rodents*, which include mice, rats, and ground squirrels, are at times very injurious. Certain small flesh-eating mammals, weasels, for example, and a few birds are also harmful when too numerous. A large majority of the higher animals, however, must be looked upon either as beneficial, or at least as neutral, with reference to human welfare.

Vertebrates and the Control of Pests. The vertebrates play a highly important part in nature in the maintenance of the balance between the various groups of living things. Animals from every class of vertebrates are active in holding injurious pests in check. The birds, as a group, are by all means the most efficient in the destruction of pests, but many members of the other classes are

¹ Much of the economic material given in this and other sections of this book is based upon Farmers' Bulletins and other publications of the U. S. Department of Agriculture.

definitely beneficial from this standpoint and should receive some attention.

Fishes and Pests. It has already been pointed out in the discussion of the mosquito on page 417 that certain entire groups of small fishes, notably the minnow family, and the young of many other species, are very important in the destruction of mosquito larvæ. Nothing further need be said upon this point except that some other aquatic insect larvæ are likewise destroyed by fishes; but most of these can scarcely be considered pests.



FIG. 221. — CORNSTALK RUINED
BY BROWN RATS

(From Weed's *Farm Friends and Farm Foes*, page 319)

tained by means of the tongue. This organ is attached at the front of the mouth with the free end pointing backward; however, the animal can dart it out with lightning-like rapidity to a distance of an inch or more. The forked end is covered with a glutinous secretion that serves to hold the insect with which it comes into contact. When any moving insect, be it fly or cutworm, comes within range of this weapon, there is a slight movement almost too quick for the eye to follow, and the unfortunate victim disappears as if by magic.

Value of the Garden Toad. The common garden toad is an extremely beneficial animal from the standpoint of garden and field

Amphibians and Pests. The larvæ of the amphibians feed upon vegetation, but the adults subsist mainly upon animal foods, and in some cases are important agents in the extermination of injurious insects.

Food Habits. The food of frogs and toads, which are the amphibians chiefly concerned in the destruction of insects, is ob-

crops. Few people who see these animals hopping about in the cabbage patch or flower bed realize the amount of protection they afford growing plants. In fact, the toad is likely to be looked upon as an obnoxious creature because it is said to "cause warts," a belief which has no foundation whatever.

The toad feeds mainly upon injurious insects, such as cutworms, caterpillars, grasshoppers, and various others which come in its way as it hops about the gardens and fields. Very often numbers of toads may be found during warm summer evenings in the vicinity of street lights, where insects of many species are abundant.



FIG. 222. — MEADOW MOUSE

When numerous these rodents do much damage in the fields. Hawks and owls destroy large numbers of them. (From *Weed's Farm Friends and Farm Foes*, page 312)

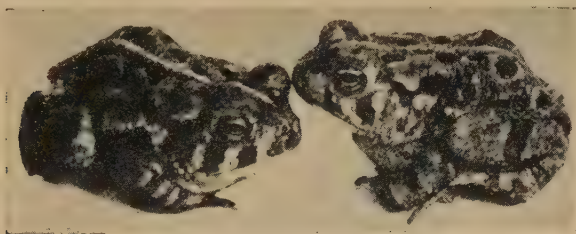


FIG. 223. — ONE-YEAR-OLD TOADS

(Reprinted from *The Frog Book* by Mary C. Dickinson, published by Doubleday Page and Company. By permission)

The Toad's Capacity for Food.¹ A specimen that was carefully observed for twenty-four hours consumed a quantity of insect food equal to about four times its stomach capacity. A single stomach that was examined contained the following: six cutworms,

¹ Data from *Farmers' Bulletin No. 196, Usefulness of the American Toad*, U. S. Department of Agriculture.

six sow bugs, five thousand-legged worms, nine ants, one weevil, and one ground beetle. According to this, in ninety days a single toad would destroy nearly 10,000 injurious and noxious insects. The cutworms alone would amount to more than two thousand individuals. When one considers how harmful these insects are to young plants, the true economic value of the toad at once becomes apparent. At a penny apiece, the price a gardener sometimes pays for the destruction of these insects, this toad earned more than twenty dollars in three months for the person fortunate enough to have it on his premises.

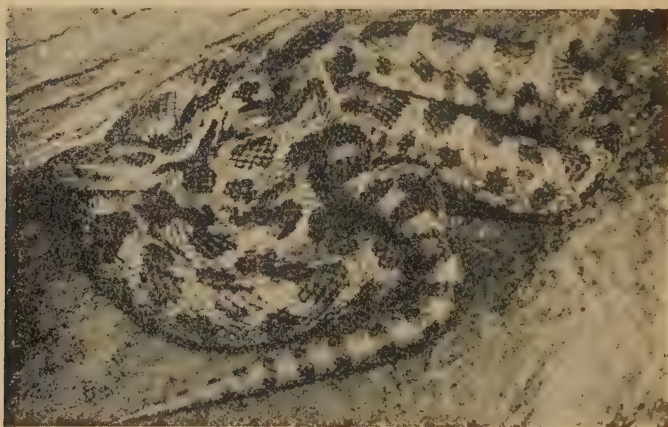


FIG. 224. — FOX SNAKE

(Reprinted from *The Reptile Book* by Raymond L. Ditmars, published by Doubleday Page and Company. By permission)

Reptiles and Pests. Some of the small reptiles, such as lizards and green snakes, destroy considerable numbers of insects; in fact, many of them live exclusively upon this food. On the whole, however, these animals are not abundant enough to be of any great importance as insect destroyers. The really valuable work of reptiles is the destruction of the smaller gnawing mammals, such as field mice and ground squirrels. The injury caused by the rodents to stored as well as to growing crops is often very great when these

animals are numerous, and since they breed rapidly when undisturbed, the necessity of holding them in check is obvious.

Many of the common snakes are very beneficial on account of their destruction of rodents in the fields and near barns and stacks of grain. Among these may be mentioned the *bull snakes*, the *fox snakes*, and the *king snakes*. In fact, practically all of our common forms are helpful. A few species sometimes destroy eggs and birds



FIG. 225. — KING SNAKE

(Reprinted from *The Reptile Book* by Raymond L. Ditmars, published by Doubleday Page and Company. By permission)

in the nest, but this should not be held too strongly against them; for, doubtless, in a large majority of cases, the good done in the destruction of small mammals far outbalances the bad. A few snakes are poisonous and consequently dangerous, but this matter will be discussed later.

The Prejudice against Snakes. A clear understanding of the habits and the value of snakes in general will accomplish much in removing the unreasonable prejudice existing almost everywhere against them. With the majority of people, the first and uppermost idea upon seeing any kind of a snake is to kill it. Consequently, many of these valuable creatures are destroyed annually. A fox snake, for example, that has taken up its abode near a wheat stack or in a farm yard is generally killed at sight; nevertheless, this

animal is far more valuable to the farmer than his cat. The snake destroys large numbers of mice and rats and does no injury, while the domestic cat, although it may catch these rodents, far offsets the good it does by the destruction of young birds in the late spring and early summer months.

Poisonous Reptiles. Poisonous reptiles are confined chiefly to the group of snakes. Contrary to the popular impression, snakes in



FIG. 226. — DIAMOND RATTLESNAKE

(Reprinted from *The Reptile Book* by Raymond L. Ditmars, published by Doubleday Page and Company. By permission)

general are not poisonous. In the United States only a few are known to be deadly.

1. The most important of these are the *rattlesnakes*, which include a number of species widely distributed over the country. These range in size from the great diamond rattlers of the southern and western states, which may attain a length of seven or eight feet, to small types less than two feet long. All are looked upon as dangerous.

2. The *copperheads* compose a single species. Though not very numerous, they may be found at times along streams or in rocky ravines, even in well-settled regions. These snakes are never very large, seldom reaching three feet in length. Nevertheless they are quite deadly and should be avoided with great care. (Fig. 228.)

3. The deadly *water moccasin*, or "cotton mouth," as it is sometimes called, is one of the most vicious and dangerous of our snakes; for, unlike the rattlers, it is said to attack without any warning whatever. The range of this reptile is confined to the swampy regions of the southern states; seldom is it found north of the Ohio River. This species is very different from the common and harmless water snakes of the northern states, often referred to as "moccasins." (For an adequate discussion of these interesting and important reptiles the student must be referred to some special treatise on the subject.) (Fig. 229.)

The Importance of Birds in the Destruction of Pests.

As a result of the effective warfare waged by birds of many species upon insects and other pests, this class of vertebrates should be accorded first place in the destruction of injurious animals. Certainly no other group can compare with them, except, perhaps, the parasitic and predacious insects discussed in Chapter XIII. Adverse weather, and insect diseases are also effective at times in checking pests, but these (and the same is true to a certain extent with insect parasites) are influential often at more or less remote intervals. Insectivorous birds and other species that are active in the control of vertebrate pests, on the other hand, are likely to carry on a constant war upon them.

Locomotion and the Efficiency of Birds. The power of flight is one of the most important characters that determine the effectiveness of birds as pest destroyers. Unlike most other animals, they, as a group, have almost boundless feeding grounds. A snake or a toad, for example, may spend its entire life in a small garden or a field of a few acres, and, although it is quite effective in these restricted areas, its beneficial influence is limited. The field mice or cutworms may be controlled in the immediate feeding grounds,



FIG. 227. — DISSECTION OF HEAD OF RATTLESNAKE SHOWING FANGS (f) AND POISON SAC (p) (From Colton's *Zoölogy*, page 204)

while, a few hundred rods away, they may be sufficiently numerous to cause great injury. This condition arises from the fact that the toad and the snake are definitely handicapped by their limited powers of locomotion. If the animals upon which they feed become scarce, they cannot migrate to distant fields where food is more abundant.

How different is the bird! With its remarkable powers of flight the immediate range is often very great. The red-tailed hawk, for

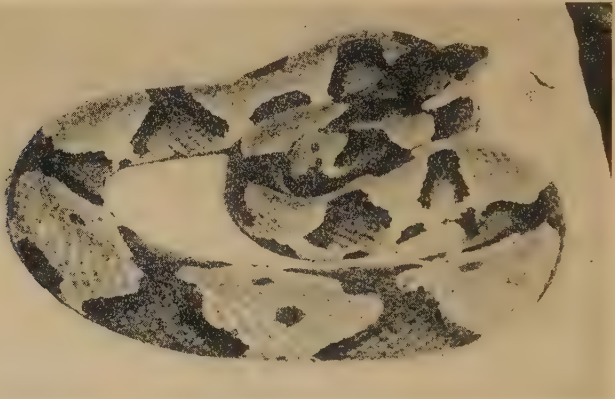


FIG. 228. — COPPERHEAD

(Reprinted from *The Reptile Book* by Raymond L. Ditmars, published by Doubleday Page and Company. By permission)

example, that feeds largely upon rabbits and other small rodents often covers several square miles of territory, and may migrate, in a few hours, to new feeding grounds many miles away, if the chosen food becomes scarce in one locality. The same, in general, is true of many of our smaller birds, but with these the ranges are limited, especially during the breeding season.

Variety of Food and Insect Control. Another important factor relative to the efficiency of birds in the control of pests is the fact that the different species generally feed upon a rather wide variety of food substances. Crows, for example, may feed to a considerable extent upon field mice in the winter, when they are

abundant about corn shocks, but may choose locusts for a large portion of their food in summer, when these insects are numerous.

A large number of birds feed upon the food that is most easily obtained. When locusts, for example, become abundant enough to do injury, many species of birds change from their ordinary foods and prey upon these pests, thus reducing them in number. As these insects become scarce in the locality, the birds shift to some other



FIG. 229. — WATER MOCCASIN

(Reprinted from *The Reptile Book* by Raymond L. Ditmars, published by Doubleday Page and Company. By permission)

food that is secured with less difficulty. The behavior of the *sea gulls* in the early history of Utah affords an excellent example of this change in food habits. Gulls usually feed upon fish and other products from the water, but when crickets became excessively abundant and threatened to destroy all the crops of the early settlers in this region, the gulls collected from all directions and in a very short time destroyed the pests and saved the crops.

The Importance of a Wide Range of Food Substances. The ability to change from one food to another, which is so striking in birds, is often lacking in the predacious and parasitic insects. Excellent examples of this type are the ladybird beetles and the parasites of the cabbage butterflies, discussed in Chapter XIII. When their special food supply diminishes, these forms decrease in

number; with birds this does not generally occur. When the pest is destroyed, the bird shifts its diet to other foods or migrates to other fields and *thus escapes self-destruction as a result of the exhaustion of its own special food supply.*

Activity of Birds. Many birds are much more active than most of the other higher animals. A large number of species continually move about during the day time, not sluggishly, as is often the case with mammals and reptiles, but with great rapidity. Some, as the swallows and swifts, are on the wing a large part of the time, and probably fly hundreds of miles daily in obtaining their food. Others fly long distances to and from the feeding grounds, and during the day many of our common song birds are constantly hopping and flitting about in the trees. The size of the heavy "breast" muscles used in flying indicates the amount of power needed by the birds.

Amount of Food of Birds.¹ Judging from the great activity of birds in general, one would expect the amount of food taken to be very large; for, as has been stated, all energy in living things is derived from this source. It is not surprising, then, that birds do have voracious appetites; but the actual amount of food consumed in many instances is almost beyond belief. (Fig. 230.)

The stomach contents of many birds have been studied with great care and the results obtained are extremely instructive from the standpoint of the value of birds in the control of pests. In the stomach of one yellow-billed cuckoo the remains of two hundred and seventeen fall webworms were found, and in that of another there were two hundred and fifty tent caterpillars. Five hundred mosquitoes were present in the stomach of one night hawk, and sixty grasshoppers in that of another. If space permitted, statements of a similar nature might be made regarding many other species.

Other studies have been made upon the total quantity of insects destroyed by the birds of a given region. It has been estimated by careful observers that in the State of Pennsylvania the birds destroy

¹ Much of the material upon the value of birds has been obtained from *The Utility of Birds* by Forbush, as well as from Farmers' Bulletins. See Bibliography.

nearly 3,000,000,000 insects daily, and in Nebraska, one hundred and seventy carloads of them.

Birds and Food Products. It should also be noted that when a bird feeds upon grain or other valuable products it is highly injurious, because of its remarkable appetite. It is indeed fortunate that so few birds are guilty of this habit. Moreover, this generally

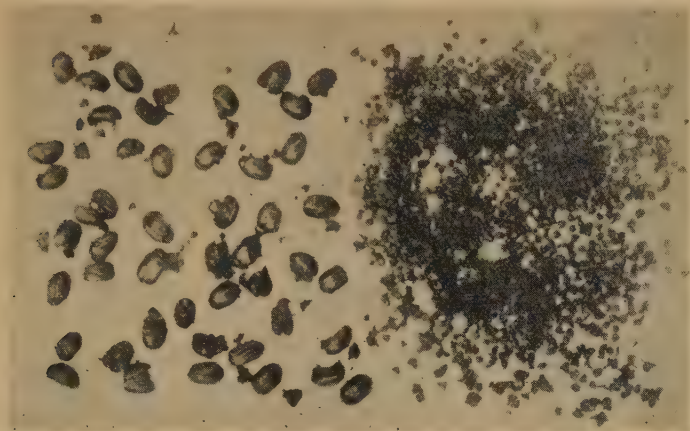


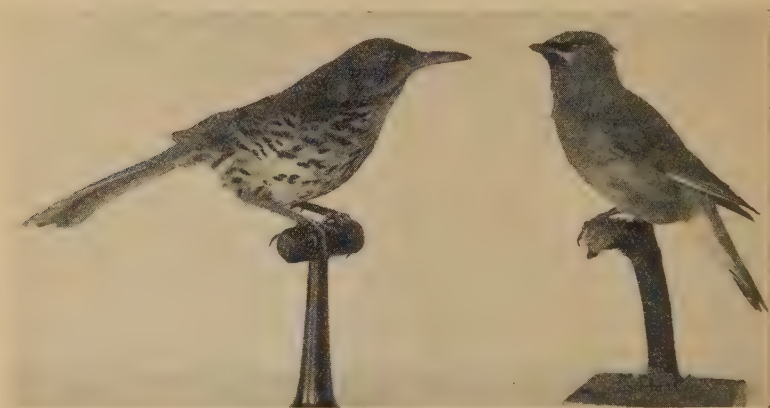
FIG. 230.—CONTENTS OF A BOBWHITE'S CROP

Forty-eight potato beetles and about two hundred and fifty weed seeds. (From Forbush's *The Domestic Cat*. By permission)

occurs only for a short time during the season; the greater part of the year is usually spent in protecting rather than in destroying products. The few cherries that a robin eats during cherry time surely should not condemn this valuable bird; for during all the rest of the year it is extremely efficient in exterminating great numbers of harmful insects. (Fig. 231.)

Food of Young Birds. The habits of birds during the nesting season are very significant relative to the destruction of insects. Practically all of our birds, except the ones that subsist habitually upon flesh, as do many hawks and owls, feed the young upon insects. Even those which, like many of the sparrows, depend largely upon seeds, are not exceptions to this rule.

Nesting Season and Insect Destruction. The habit of feeding the nestlings upon insects has far-reaching consequences. At the time when the young are being reared — that is, during the spring and early summer months — the parent birds capture immense numbers of insects. The destruction of them at this season not only does away with the mature forms but also prevents the tremendous increase that would have resulted during the summer had these individuals survived. For example, the bird that destroys



Brown thrasher

Cedar waxwing

FIG. 231. — THESE BIRDS SOMETIMES EAT CHERRIES BUT THE GOOD THEY DO IS FAR GREATER THAN THE HARM (Original photograph)

an adult aphid in May prevents the countless thousands of possible descendants from injuring vegetation in August.

Another point concerning the feeding of young birds in the spring is the fact that many insects are thus destroyed while still in the young larval stages, and, consequently, before they have had time to consume much food. It should also be noted that early in the season when the larvæ are minute, large numbers of certain types are required to satisfy the bird's appetite. Later, when the insects have about attained their growth, a relatively small number are taken at a meal.

It is interesting to observe the reduction in a brood of leaf-eating caterpillars that ordinarily takes place during the development of

these larvæ. While hundreds may be hatched from the eggs, it often happens that relatively few reach the pupal stages unless the insects are especially protected by hairs, webs, or in some other way. This reduction is to be attributed chiefly to birds, although other destructive agencies also play a more or less important part during the period of larval growth.

The Quantity of Food Eaten by Young Birds. Nestling birds grow with great rapidity and therefore require large quantities



A Warbler

A Vireo

Chickadee

A Kinglet

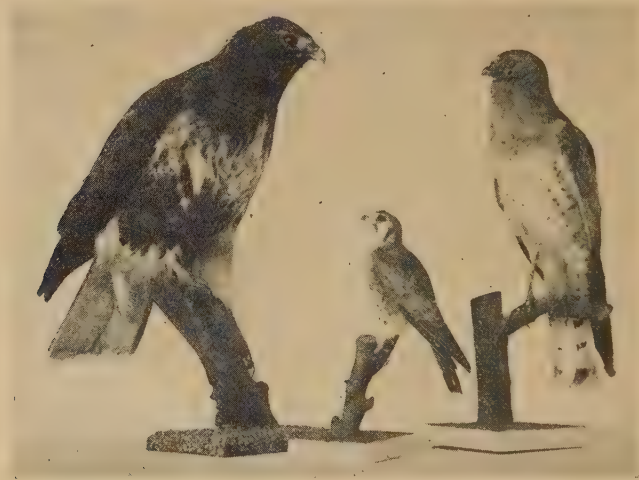
FIG. 232. — SMALL BIRDS THAT DO A VAST AMOUNT OF GOOD THROUGH THE DESTRUCTION OF SMALL INSECTS (Original photograph)

of food. When they leave the nest, song birds are generally as large as the adults. This growth takes place in from ten days to three weeks after the time of hatching. A young robin on the fourteenth day after hatching ate sixty-eight angle worms and some time later consumed "in a day nearly one-half its own weight of beef." At this same rate a young person weighing one hundred and fifty pounds would require seventy-five pounds of beef per day. Another young robin was fed from fifty to seventy cutworms per day for a considerable period, and on one day during an experiment it consumed one hundred and sixty-five cutworms.

The capacity of young birds for food is explained to a considerable extent by the fact that their rapidity of digestion is very great. It

is said that the stomach may be emptied of food in from twenty minutes to two hours.

Small Birds and Insect Destruction. The small birds, such as the warblers, kinglets, and chickadees, are very effective in the destruction of insect pests. A large bird, the rose-breasted grosbeak, for example, that destroys the beetles in the potato patch where they are damaging the crop, is doing work that can be easily observed. Consequently, the bird is given full credit for the good it accomplishes. On the other hand, the beneficial results achieved



Red tailed hawk

Sparrow hawk

Marsh hawk

FIG. 233. — THESE HAWKS DO MUCH GOOD

They should not be killed. (Original photograph)

by the tiny warblers and chickadees, that are ever active in the destruction of insect eggs or of the minute, newly-hatched larvæ, are not nearly so noticeable; for the insects upon which these birds feed are generally too minute to attract attention. The truth is, however, that such birds are tremendously effective, for they often destroy the pests before injury is done. Moreover, the numbers taken at a meal are very great because of the minute size of the insects or eggs, as the case may be. (Fig. 232.)

Hawks and Owls as Destroyers of Rodents. Many of the larger birds of prey belonging to the group of hawks and owls destroy countless numbers of rodent pests, such as mice, rats, ground squirrels, and rabbits. The recognition of the true value of these birds by people in general is especially important because of the wide-spread prejudice against them as a group. The attitude



FIG. 234.— THESE OWLS DO MUCH GOOD THROUGH THE DESTRUCTION OF MICE AND OTHER RODENTS

(Original photograph)

toward hawks and owls is much the same as the feeling against snakes. The whole group is looked upon, even by many thoughtful people, as definitely harmful and consequently deserving of destruction. This idea is largely incorrect. A few species, namely, Cooper's hawk, the sharp-shinned hawk, and the great horned owl, are destructive to poultry or song birds and probably should be killed whenever possible; but the *great majority of hawks and owls are very beneficial and deserve to be protected.* (Figs. 233, 234, 235, 236, and 238.)

Practically all of the birds of this group, except those mentioned above, feed largely upon rodents, or upon other animals that are of no direct value to man. There are cases on record where a bounty

placed upon the heads of hawks and owls led to the destruction of large numbers of them, which resulted in an increase of field mice and other rodents until they caused serious injuries to crops. Since hawks and owls certainly play an important part in holding these animals in check, man should not interfere with this natural relationship.

Birds and Weeds. The beneficial effect of birds in controlling weeds is worthy of notice. The seed-eaters, notably the sparrow family, are the most important in this respect. Many of these birds remain in cold climates over the winter and at this time feed almost exclusively upon weed seeds. It has been estimated by a competent authority that tree sparrows alone, in the state of Iowa, destroy in the neighborhood of eight hundred and seventy-five tons of weed seeds during each winter. When it is considered that this is accomplished by a single species, the total amount of protection afforded by all the winter birds that feed upon seeds is, to say the least, rather impressive. (Fig. 237.)



FIG. 235. — GREAT-HORNED OWL, DESTRUCTIVE TO POULTRY (Original photograph)

Money Value of Birds. Even though it is a well recognized fact that birds are great destroyers of pests, their real money value is often not appreciated. In 1918 Dr. A. O. Gross made careful investigations of the food habits and abundance of dickcissels in Illinois. He concluded that through the destruction of grasshoppers, these birds, during their nesting season, daily saved the farmers \$4680.00 worth of hay. W. T. Hornaday, an eminent authority on wild life, states that each woodpecker in the United States is worth twenty dollars, and each nuthatch or chickadee, from five to ten dollars. Theodore Roosevelt on one occasion made a report to Congress in which it was estimated that a single species of

hawk (Swainson's), a bird found in a limited district of western United States, is worth more than \$57,000 each year to the farmers of that region, through the destruction of grasshoppers.¹ (Fig. 239.)

Mammals and Pests. Mammals, in general, are not of any great importance in the control of insect pests. A few, such as



Goshawk

Sharp-shinned hawk

Cooper's hawk

FIG. 236.—THESE HAWKS ARE DESTRUCTIVE TO POULTRY
(Original photograph)

bats, shrews, moles, and some of the larger forms, feed exclusively upon insects, or at least use them as their main food supply; but the direct benefit from these animals as pest destroyers is not great. The smaller carnivorous types of mammals, such as weasels, minks, and foxes, when relatively abundant, destroy rabbits, ground squirrels, field mice, and other injurious rodents, when these are numerous enough to be classed as pests. However, the objectionable charac-

¹ From *The Utility of Birds* by Forbush. See Bibliography.

ter of these flesh-eating animals manifests itself when, as a result of the failure of the natural food supply, they turn their attention to poultry, and sometimes cause great losses. Dogs and cats also are of value in holding rodents in check.

Cats and Birds. The beneficial results achieved by cats through the destruction of rodents are far surpassed by the injury they do through feeding upon young birds and adults during the breeding season. It should be said in justice to the cat that a well-fed pet that remains about the house continually may do but little or possibly no damage. Cats of this type, however, are extremely rare. It is agreed by authorities that stray cats and the pets that wander away in the fields and woods are inimical to bird life.



Tree sparrow Chipping sparrow Fox sparrow Song sparrow

FIG. 237.—SPARROWS ARE SEED EATERS AND DESTROY VAST NUMBERS OF WEED SEEDS DURING THE WINTER MONTHS (Original photograph)

The great destructiveness of the house cat is the result of several well-defined factors. 1. These animals are sufficiently numerous to do much damage, for the cat population is far greater than it is usually supposed to be. In rural districts and even in towns there are often a large number of cats, which, when not fed sufficiently, wander away and forage for themselves. 2. It is the nature of the cat to capture its prey alive. Long domestication has changed this character but little. In a hungry cat the wild nature inherited through countless generations of ancestors is bound to assert itself.

3. The young birds as they leave the nest are generally practically helpless, so far as escape from their enemies is concerned, and, consequently, fall an easy prey to the wandering cat. (Fig. 240.)

Litters of feathers scattered about fields and orchards during late spring and summer all too often offer mute evidence of the destructiveness of the house cat. One pet cat was known to have killed fifty-eight birds in one year. If it is true that our song birds are valuable and should be protected, then there is no escape from the conclusion that *all stray cats should be destroyed*.¹



FIG. 238. — FIELD-MOUSE SKULLS TAKEN FROM PELLETS FOUND UNDER OWL ROOST IN SMITHSONIAN TOWER, WASHINGTON, D.C.

(From *Farmer's Bulletin* 670, U. S. Department of Agriculture. By permission)



Downy woodpecker

Brown creeper

Nuthatch

FIG. 239. — THESE BIRDS DO MUCH GOOD DURING THE WINTER BY DESTROYING THE EGGS, LARVÆ, OR PUPÆ OF INSECTS UPON THE TRUNKS AND LIMBS OF TREES (Original photograph)

¹ *The Domestic Cat* by Forbush, published by the Massachusetts State Board of Agriculture, Boston, gives a large amount of material upon this subject.

Vertebrates and Disease. We have referred to vertebrates a number of times in the earlier pages of this book in connection with the transmission of human diseases. Dogs are the chief means by which rabies is spread. Some of our domestic animals, notably cattle and hogs, are looked upon as being responsible for at least a certain percentage of tuberculosis cases, especially in young children. Various "worm" diseases are also disseminated by these



FIG. 240. — THE DESTRUCTIVE HOUSE CAT

This well-fed pet was known to kill fifty-eight birds in one year, including the young in five nests. From Edward Howe Forbush. Photograph by Mr. A. C. Dike, first published in *Useful Birds*. By permission)

animals as well as by fishes and dogs. Rats and other rodents are definitely concerned with the transmission of bubonic plague, a scourge of the Asiatic countries. There is also a probability that during epidemics pet animals, such as cats and dogs, scatter the germs of such diseases as diphtheria among small children with whom these animals come in contact.

GEOLOGICAL HISTORY OF THE VERTEBRATES

The vertebrates as a group have existed upon the earth for a vast period of time; no one knows just how long, but without doubt many millions of years have elapsed since the first simple forms appeared. The facts concerning these early animals have been learned through the fossil remains preserved in the strata of rocks that were in process of formation in those ancient times. The characters and abundance of fossil forms have made it possible for the geologists to work out in considerable detail the history of the vertebrates from their earliest appearance up to the present.

Time of Appearance of the Various Classes of Vertebrates. The order in which the classes of vertebrates, as we have them today, appeared upon earth is clearly indicated by the occurrence of their fossil remains in the very ancient rocks. The *fishes* made their appearance first and became abundant in the seas. In later times these animals were less prominent, and certain types of *amphibians* evolved. In turn the amphibians gave place to gigantic *reptiles* that for a long period dominated the animal life of the earth. Finally, most of the reptiles disappeared and the great prehistoric *mammals* came into existence. They roamed the earth for ages, but they too became extinct. During recent geological times, a period of many thousands of years, the mammals of the present day developed.

It is a significant fact that the lowest vertebrates appeared first, and that these forms were followed during the successive ages by more and more complex types until finally the mammals evolved, the most highly developed of all.

Age of Fishes. The abundance of the fossil remains of the early fishes in the stratified rocks indicates that these animals were for a long time the dominant vertebrates upon earth. Hence they gave the name to this particular period. In fact, in the earlier layers of rocks containing the fossils of the fishes no other vertebrates are found. The most ancient fishes belonged to the lower types, which are characterized by cartilaginous rather than bony skeletons, and were closely related to the sharks and rays of the

present day. Later, fishes appeared that were covered with resistant bony plates and were akin to the modern garpikes and sturgeons. Representatives of the higher fishes, such as the perch, the bass, and most of our other food fishes, were not in existence during these early times, but developed during the succeeding geological periods.

Certain types of fishes that breathed, in part at least, by means of lungs occurred abundantly in these ancient geologic ages. Some of them still exist as the lung fishes of Australia and South America. It is also interesting to note that the "dogfish," or bowfin, of our rivers, which is related to some of these ancient forms, is able to



FIG. 241. — LUNGFISH (From Colton's *Zoölogy*, page 179)

utilize air to a limited extent by means of its "swim bladder"; for it can live almost indefinitely in a small quantity of water from which a large percentage of the dissolved oxygen has disappeared.

Age of Amphibians. In the epoch following the age of fishes, great swamps appeared in the interior of what is now North America, and luxuriant tropical vegetation flourished, giving rise to the coal beds of today. Some of the fishes, as well as the invertebrates, continued to exist; but the most characteristic animals of this period were the lower amphibians. Some of them were snake-like in form and others possessed legs. These animals never became dominant, like the reptiles and mammals. The higher amphibians, such as the frogs and toads, did not come into existence until later times.

There is evidence that the amphibians developed from certain types of fishes during this ancient period. The first representatives of the group of reptiles made their appearance at about the same time, geologically speaking, as the earlier amphibians. Whether this class evolved from a primitive amphibian type or from some simpler form that gave origin to the amphibians as well is not entirely

clear. For our purpose, however, it is sufficient to note that both the amphibians and reptiles originated from lower types of land-frequenting vertebrates.

Age of Reptiles. While the amphibians were still abundant the typical reptiles appeared. These forms increased in number, in size, and in power until finally they dominated the sea and the land. Some of them were relatively small-headed and possessed long necks and tails, while others were shorter but had tremendously bulky bodies. The reptiles either swam in the water or walked along the shores. In some cases they walked on all fours, and in others the body was supported upon the enormous hind legs. Certain types were heavily armored, bearing bony plates that covered the body as well as the tail. One of these recently described in the magazine, *Natural History*, was truly a "super-dreadnaught" of the ancient world. Flying reptiles of smaller size were also in existence.

The size of the largest of these reptiles is almost beyond belief. Some were doubtless the most colossal animals that ever lived on land, and it is said that they rivaled or even surpassed in size the largest whales known. One type, an *herbivorous dinosaur*, was nearly a hundred feet in length and possessed a body certainly several times the bulk of the largest elephant. A related form, a *carnivorous dinosaur*, supported its body upon its massive hind legs and apparently was an active and savage creature. It was nearly twenty feet in height and, although not so large as the form mentioned above, was of immense size. The head was over four feet long and the jaws were provided with great teeth. The hind feet were armed with huge nails about eight inches long. One authority states that this was probably the most powerful and destructive creature that ever existed.

Ancient Birds. About the time that the reptiles were abundant, the first known birds appeared. The fossil remains of the earliest type known are so well preserved and so complete that they indicate unmistakably the true nature of these ancient forms. Judging from one specimen, which was about the size of a crow, these creatures had beaks set with true teeth and possessed backbones that extended into the tail, as in the case of the reptiles of to-day.

The body was covered with feathers and the wings resembled those of the modern birds, except that claws were present which apparently were of use in climbing. The tail was a remarkable structure composed of about twenty vertebræ with a pair of feathers attached to each in a vertical plane. During later times these early types gave rise to the birds now in existence.

Age of Mammals. As the great reptiles become extinct, the first mammals began to appear. They were allied to the *duckbill*,



FIG. 242. — DUCKBILL (From Colton's *Zoölogy*, page 256)

that peculiar animal of Australia that reproduces by means of eggs, and to the *marsupials*, the group to which the opossums belong. These mammals were of small size, and there is evidence that they evolved from comparatively simple reptilian forms. As the time went on, larger and more complex types developed, culminating in the great mammoths, mastodons, giant elks, rhinoceroses, and saber-toothed tigers, the remains of which are so well known in museums of natural history. These huge beasts roamed over North America and other continents for a long period, and were present here during the Glacial Epoch, when the successive ice sheets advanced, covering the northern and central portions of the continents of the northern hemisphere.

Many of the great mammals disappeared during comparatively recent geological times, and from those that persisted, the present

day forms developed. The origin of the horse, discussed in Chapter XI, is an excellent example of the way in which our modern animals, in general, have come into existence.

The Meaning of the Geological History of the Vertebrates. Summary. The geological evidence cited above is of great import. First the lowest class of vertebrates, the fishes, appeared upon earth, then the amphibians, then the reptiles, and lastly the mammals. Each class came into prominence in turn, then decreased in importance, but persisted to the present time, giving us our modern vertebrates. Birds were never dominant, but the ancient forms continued to develop and finally gave rise to those we have about us to-day.

As we go back from the complex and highly developed animals of the present, we find simpler and simpler types until we come to the earliest representatives of the different groups. In some remarkable cases we discover intermediate fossil forms that connect the various classes of vertebrates, as for example, the ancient bird which possessed characters of both birds and reptiles. There are a number of other fossil forms that serve to show the relationship existing between different groups of vertebrates. Moreover, the air-breathing lung fishes and the egg-laying mammals, such as the duckbills, are extremely significant in this connection. Finally the fish-like tadpoles that develop into toads and frogs indicate unmistakably that a water-inhabiting creature can give rise to a land animal. All of these facts, together with the similarities in structure and function of the various organs in the different classes of vertebrates, point with certainty to the *common origin and definite relationship of these animals*.

Law of Development. The facts brought out in the preceding pages, with much additional evidence that cannot be cited here, justify a broad statement concerning the development and relationship of living things: *During the vast periods of geological time, not only the vertebrates but all animals and plants as we have them to-day have developed from simpler and more generalized types which existed ages ago upon earth.* This law of development is generally referred to as *Organic Evolution*.

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INDEX

- Abdomen, 288
- Absorption, 77, 86, 296
- Action of heart, 298, 302, 389
- Adenoids and health, 277
- Age of amphibians, 468; of fishes, 467; of mammals, 470; of reptiles, 469
- Agriculture, 108, 155
- Air bladder of fishes, 441; in lungs, 307; in soil, 117; spaces in plants, 76; tubes of grasshoppers, 390
- Albumen of eggs, 63, 445
- Alcohol, 198, 283
- Alcoholic fermentation, 194
- Algæ, 165, 368
- Alum and water purification, 232
- Amœba, 360
- Amphibians, 437, 448, 468; and pests, 448-450
- Ancestor, influence of an, 357
- Anger and digestion, 294
- Animal and plant compared, 359; breeding and heredity, 325, 340; cell, 93, 360; many-celled, 367, 370
- Annual rings, 127
- Annuals, 90
- Antennæ, 288
- Anthers, 22, 23
- Anthrax, 234
- Antiseptics, 219; and open sores, 283
- Antitoxin, 243; diphtheria, 265-268; tetanus, 282
- Ants, actions of, 424, 426, 433
- Aorta, 301
- Aphids, 400-403
- Appendix, 290, 297, 439
- Apple, 40, 120, 136
- Arteries, 300, 301
- Arthropods, 386
- Asexual reproduction, 136-138
- Aspergillus, 176
- Athens, decline of, 347
- Auto-intoxication, 297
- Available elements, 156
- Backbone, 436
- Bacteria, 203-286; and disease, 233-286; and legumes, 158-162; and open sores, 279-283; and pus formation, 279; effect of, in body, 241; food of, 203, 206, 210; importance of, 203; in air, 225-227; in dust, 226; in ice, 217; in soil, 158-162, 227; in vinegar, 198, 205, 224; in water, 228-232; multiplication of, 208; occurrence of, 205; pathogenic, 236; size and multiplication of, 203, 204, 208; spores of, 209; structure of, 206; types of, 207
- Bactericidal substances, 243
- "Balance in nature," 418-424
- Barberries, 187
- Barberry rust, 186
- Bark, 125, 128
- Bean study, 40, 47
- Bees, 424, 426, 433
- Behavior of plants and lower animals, 424-433; of higher animals, 433-435; of man, 434

- Biennials, 91
 Bile, 255, 296; duct, 295
 Birds, 438, 453-465; activity of, 456;
 ancient, 469; and destruction of
 food products, 457; and insect con-
 trol, 454; and pests, 453; and
 rodents, 461; and weeds, 462; effi-
 ciency of, 453; food habits of, 454-
 456; food of young, 457-459; quan-
 tity of food, 456-459; money value
 of, 462; nesting season of, 458
 Bites of animals, 283
 Black rust, 186
 Bladder worms, 379
 Blades of grass, 16
 Bleaching powder and water supplies,
 232
 Blood, 299-304; composition of, 300;
 functions of, 299; poisoning, 280;
 red corpuscles of, 300, 306; vessels,
 300; white corpuscles of, 242, 300
 Blue mold, 176
 Body temperature, 275, 439
 Bordeaux mixture, 192
 Braconid fly, 405
 Bracts, 20
 Brain, 391, 443, 444; intelligence and
 size of, 443
 Bread making, 199; mold, 170-176
 Breeding habits and animal control,
 413
 Broken branches and decay, 133
 Bubonic plague, 417
 Bud, 121-122
 Budding, 133; in yeasts, 194
 Bulk in diet, 296
 Burbank, 338
 Cabbage butterfly, 403-405, 408; and
 parasites, 405, 408
 Calories, 311
 Calyx, 20
 Cambium, 127, 132
 Candy in diet, 313
 Canning of fruits, 215
 Capacity of lungs, 308-309
 Capillaries, 296, 301
 Carbohydrates, 58-62; in diet, 312-
 314
 Carbolic acid, 222
 Carbon dioxide in dough, 199
 Care of wounds in trees, 133, 179
 Cats and birds, 464, 465
 Cattle and tuberculosis, 250
 Cell, 91-100; division, 97; sap, 96;
 unit of function, 100; unit of struc-
 ture, 92; wall, 93, 94
 Cellular structure, 92
 Cellulose, 58, 94; in diet, 58, 94, 296
 Centipedes, 386, 387
 Cesspool contamination, 256-260
 Chalcis fly, 406
 Cheese, production of, 176
 Chest, 288
 Chewing of food, 291
 Chlorine and water purification, 232
 Chlorophyll, 145-148
 Chloroplasts, 145
 Cholera, 239
 Chromatin, 97
 Chromosomes, 97-99; and heredity,
 99, 335, 336
 Chrysalis, 403
 Cider, 198
 Circulation, 299-304, 440-441; and
 exercise, 302; in amphibians, 440;
 in fishes, 440; in man (embryo),
 445; in reptiles, 441
 Clay in soil, 112
 Coagulation of proteins, 63
 Cocklebur, 40
 Cold pack canning, 216; storage, 217
 Colds, 273-278; and body resistance,
 276-278; and open air, 274; germs
 in the body, 274; importance of,
 273

- Colon, 289, 295, 297
 Combinations of hereditary characters, 336
 Commercial fertilizers, 163
 Compressed yeast, 200
 Congestions, 275
 Constipation, 297
 Contact and colds, 238, 274; and typhoid, 258; pollination, 25
 Control of bacterial growth, 211-225
 Cooper's hawk, 461, 463
 Copperhead, 452
 Cork cambium, 128
 Corn belt, 11
 Corn plants, 9-18; origin of, 10
 Corolla, 20
 Corpuscles, red and white, 300
 Corrosive sublimate, 222
 Cotyledons, 46
 Coughing and disease, 238
 Cowpox, 270
 Criminality in "Jukes," 353
 Cross-pollination, 24
 Crustaceans, 267, 386
 Culms of grasses (stems), 14
 Cultivated yeasts, 196
 Cultivation and roots, 13
 Cuticle, 125
 Cytoplasm, 97; and heredity, 337

 Darwin, 376
 Decay, 210
 Deep breathing, 307
 Deficient elements, 157
 Demons and disease, 233
 Determiners of characters, 331, 335
 Dextrines, 69, 291
 Diaphragm, 288
 Dicotyledons, 46
 Diet, 310-322; food required in, 311
 Diffusion and osmosis, 100-108; in animals, 107
 Digestion, 65-69, 290-299; and exercise, 298; and mental states, 293; definition of, 66; glands of, 290; in earthworms, 374; in hydra, 372; in small intestine, 296; in sponge, 371; in starfish, 373; organs of, 288, 439; systems of animals, 374, 439
 Dinosaur, 469
 Diphtheria, 261-268; antitoxin, 263-268; bacteria in body, 263; direct contact and, 262; diseased throats and, 265; epidemics, 261; human carriers of, 264; in lower animals, 264; resistance of germs, 262; spread of the disease, 262; susceptibility to, 261; toxin, 263; types of, 263
 Disease, 233-285; contagious and infectious, 237; germs, 233, 243, 365; transmission of, 237
 Disinfectants, 218-223
 Disposal of wastes, 229, 256, 260, 412
 Dogs and rabies, 283, 466
 Dominance, 332-334
 Drainage of soils, 118, 377
 Dressing of wounds, 283
 Drinking water, 317
 Drugs and loss of weight, 316; habit, 321; use of, 322
 Dry weather and crops, 115
 Dry yeast cakes, 200
 Ducts, 126, 288
 Dust and disease, 218, 226

 Ear of corn, 17
 Earthworm, 374, 376-378; and soil, 377
 Edwards and "Jukes" contrasted, 353
 Edwards family, 351-354
 Egg cell, 32-33, 335-337, 443
 Eggs of vertebrates, 445, 470
 Elements of plant growth, 155-163
 Elizabeth Tuttle, 352
 Embryo, 35-36, 443; development of

- human, 443-446; of bean and corn, 45, 46; sac, 34
- Endosperm, 35, 46; nucleus, 34; and growth, 52
- Energy and activity, 73, 75, 311; and foods, 70-76; conservation of, 72; forms of, 71
- Environment, 323
- Enzymes, 65-69, 290; character of, 67; kinds and production of, 68
- Epidemics of typhoid, 257
- Epidermis, 145
- Erysipelas, 280
- Evaporation, 151-155
- Excretion, 305, 442
- Exercise and circulation, 302; and digestion, 298-299
- Exoskeleton, 386
- Fats, 62, 148; formation of in human body, 316; in diet, 313; stored in body, 317
- Feeble-mindedness, 328-345; in "Kallikaks," 354-357
- Fermentation, 197-198
- Ferns, 166
- Fertile soils, 155-163
- Fertilization, 32-33, 443
- Fibrovascular bundles, 125, 131, 146
- Filaments, 22
- Filters, 231
- Fishes, 417, 418, 436, 437, 467; and pests, 448
- Flagellum, 362
- Fleas, 417
- Fleshy roots, 77
- Flies and disease, 410-414; and typhoid, 258
- Flowers, 19-39; of grasses, 18, 24; parts of, 20; pistillate, 18; staminate, 17; variation of, 19
- Fluted scale, 422
- Focal abscesses, 321
- Food, 57-76; and disease transmission, 257, 412; and typhoid, 257-258; changes in seeds, 65-66; importance of, 4, 6; in human body, 310-322; in large intestine, 295; in stems, 120; in stomach, 291; nature of, 57; of birds, 376, 397; poisoning, 239; source in green plants, 147; stored in human body, 316; stored in seeds, 35, 58, 99; supply of plants, 58, 147; supply of vertebrate embryo, 445, 446; uses of, 4, 57
- Formaldehyde, 189, 191, 220
- Fossils, 467-471
- Fresh air, 306-310
- Frogs and pests, 448
- Fruits, 39-45
- Fruit canning, 215; definition of, 39; development of, 39; origin of cultivated, 340
- Fruiting bodies of fungi, 171, 178
- Fungi, 170-202
- Gas in intestines, 298
- Gastric juice, 292
- Geological history of vertebrates, 467-471
- Geotropism, 428
- Germination, 45-56; definition of, 45
- Germ cells, 32-33, 443; combinations of, 335
- Germ, protozoan, 365; theory of disease, 234
- Germs, 233, 243, 365
- Germ-plasm, 323
- Gills of fishes, 437, 441; in fungi, 179
- Glucose, 60
- Gluten, 63, 199
- Glycogen, 312, 317
- Grafting, 133
- Granulation of soils, 116
- Grasses, 0-18
- Grasshoppers, 396

- Great white plague, 244
 Green plants and foods, 4, 5, 142
 Growing point, 46, 81, 122
 Growth zones, 81, 82
 Grubs, 398
 Gulls in Utah, 455
- Hawks, 461
 Hay fever, 26; infusion, 206
 Healing of wounds on trees, 132
 Health and air, 305-310; and exercise, 299, 302; and food, 310-322
 Healthy body and disease, 251, 252
 Heart, 302
 Heartwood, 128
 Heat and mold growth, 175
 Hen's egg, 445
 Heredity, 323-358; and environment, 328; and seeds, 51-56; and tuberculosis, 249; in human families, 344-358; laws of, 334
 Hogs and trichina, 380
 Hookworm, 384
 Horse, 340-344; domestication of, 341; in England, 342; origin of, 340; production of a breed of, 343; types of, 342
 Hosts, 184, 406, 407
 House flies and disease, 410-414; food habits of, 411; life history of, 411
 Human body and disease, 251; traits and heredity, 333, 344
 Hybrids, 330
 Hydra, 372
 Hypha, 171
 Hypocotyl, 46
 Hydrotropism, 428
- Improvement in varieties of plants, 55, 339
 Indigestion, 297
 Insects, 386-417; abundance of, 388; and disease, 410-417; and pollination, 28, 378; beneficial, 387; character of, 388; circulatory system of, 389; development of, 391; digestive system of, 389; eggs of, 392; food habits of, 398, 400, 403, 406, 411, 415; injurious, 387; injury from larvæ of, 393; kinds of, 387; larvæ of, 392; nervous system of, 390; parts of, 388; pupa of, 394; reproduction of, 391; respiratory system of, 390; their importance, 386
 Instincts, 431-433
 Intelligence, 433-435
 Internodes of grasses, 10
 Interrelations of organisms, 366-369, 405, 406, 418-424
 Intestinal worms, 383
 Intestines, 288; absorption in, 296; large, 295; small, 294
 Invertebrates, 359-417
 Iodine, 223, 285
- Jonathan Edwards, 352
 Judgment, 433-435
 "Jukes," 347-351
- Kaibab Forest deer, 424
 "Kallikak" family, 354-358
 Kidneys, 290, 305, 442
- Ladybird beetles and aphids, 402; and scale insect, 422
 Law of development, 471
 Leaf scars, 121
 Leaves, 140-155; functions of, 142; grass, 16; structure, 140, 144; veins of, 141
 Legumes, 158-162
 Lice, body, 417
 Life histories of insects, 395
 Liver, 288, 296, 317
 Liverworts, 166
 Lockjaw, 266, 271, 280-282

- Saprophytes, 182
 Sauerkraut, bacteria and, 225
 Scale insects, 422
 Scions, 134
 Seals, 432
 Seed contents, 36, 165; development of, 49; dispersal of, 41-45; structure of, 46; true to type, 54
 Seedless fruits, 40
 Seedlings, 47
 Segments, 379, 386
 Segregation of determiners, 335
 Selection in Athens, 346; in plants, 338; in Sparta, 346; of seeds, 53
 Self-pollination, 24
 Sepals, 20
 Sewage disposal, 229, 239, 256, 260, 412
 Sex cells, 32, 335, 443
 Sharp-shinned hawk, 461, 463
 Shasta daisy, 337-339
 Sheath of leaf, 15
 Shelf fungi, 178
 Shoot, 122
 Sick, care of, 252, 260, 268, 276
 Sieve tubes, 127
 Silage, 225
 "Silks" of corn, 17
 Silt in soil, 112; loam, 113
 Slacked lime and bacteria, 222
 Sleeping sickness, 365, 417
 Smallpox, 268-273; and cowpox, 272; cause of, 269; transmission of, 269; vaccination for, 269
 Smuts, 188-189
 Snakes, 438, 450-455
 Soil, 108-118; and earthworms, 377; fertility, 162; formation, 108; sour, 160-162
 Somites, 386
 Sperm cells, 32, 33, 443
 Spiders, 386
 Spinal cord, 285, 443
 Spiracles, 390
 Spirogyra, 166
 Sponges, 370-371
 Spongy tissue of the leaf, 145
 Spontaneous generation, 234
 Sporangia, 171
 Spores of algæ, 167; of bacteria, 209; of mold, 173
 Spraying, 192
 Stamens, 21
 Starches, 60, 312; composition of, 59; storage of, 35, 58, 61
 Starfish, 370, 373
 Stem growth of grass, 15, 123; of corn, 15; structure, 14, 124, 131; types of, 119
 Sterile soils, 157
 Sterilization, 213-219
 Stigma, 23, 27
 Stimuli, physical and chemical, 426-431
 Stock, 133
 Stomach, 288, 290, 291, 294
 Stomates, 145
 Storage of seeds, 51
 Stored food in plants, 35, 58, 61; in body, 316
 Struggle for existence, 366-369, 402
 Style, 23
 Substratum, 170
 Sugars, 59-60; as food, 60, 313; in blood, 317
 Sunlight and disinfection, 218, 231; and health, 252
 Tapeworm, 377-380
 Tassel of corn, 18
 Teeth, 320-321
 Temperature and bacteria, 212-218; and distribution of the blood, 275; and germination, 50; and growth, 175, 201

- Tetanus, 280-282; antitoxin, 282;
 bacteria and effect on body, 281;
 germs of, 280
 Texture of soil, 111
 Thigmotropism, 429
 Thoracic duct, 296
 Thorax, 288
 Thoroughbreds, 343
 Ticks, 386
 Toads and pests, 448-450
 Tonsils and colds, 276; diseased,
 277
 Toxins, 241, 263, 281
 Trachea, 288, 390
 Transmission of rabies, 284
 Transpiration, 151, 155
 Transplanting of plants, 86
 Treatment of colds, 276; for diseases,
 early, 233; for open sores, 282
 Tree surgery, 133
 Trichina, 380-382
 Tropisms, 427-429
 Tubercles on roots, 158
 Tuberculosis, 244-252
 Tumble weeds, 43
 Turgor, 104
 Turpentine as antiseptic, 283
 Turtles, 438
 Typhoid, 252-260; and domestic ani-
 mals, 260; and flies, 258, 410-414;
 and milk, 258; carriers, 259; epi-
 demics, 257; from water, 239, 257;
 germs and water, 254; germs in
 soil, 254; how germs leave body,
 256; in armies, 253; vaccination for,
 259
 Underground stems, 124, 137
 Unit characters, 331
 Unit of antitoxin, 267
 Urinary system of vertebrates, 442
 Uterus, 446
 Utility of responses, 429
 Vaccination for smallpox, 263-269;
 for tetanus, 282; for typhoid, 259
 Vacuoles, 93
 Vascular bundles, 125-131
 Vegetables and typhoid, 258
 Vegetative propagation, 136
 Veins in leaf, 141
 Veneers, 130
 Ventilation, 305-306
 Vermiform appendix, 290
 Vertebrates, 436-471; and disease, 250,
 283, 377-383, 466; and pest con-
 trol, 447; and typhoid, 260; circu-
 latory systems of, 440; classes of,
 437-438; digestive systems of, 439;
 eggs of, 445; embryos of, 443; ex-
 cretory systems of, 442; nervous
 system of, 442; pests, 447
 Vicious cycle, 297
 Vigor of seedlings, 51
 Vinegar production, 198
 Virus of rabies, 284-285
 Vitamins, 318-320
 Waste matter, 287, 299, 305; nitro-
 genous, 314, 315, 442
 Water and bacterial development, 211;
 and germination, 49, 50; contam-
 ination, 229; in diet, 295, 317; in
 soil, 107, 113-118, 377; moccasin,
 453, 455; purification, 231; trans-
 mission of disease by, 239, 257, 379,
 383
 "Web of life," 419
 Wheat rust, 184-188
 White grub, 398
 Wilting, 86, 151, 153
 Windpipe, 288
 Wind-pollination, 25
 Winged fruits, 42-43
 Winter spores of wheat rust, 186
 Wood-destroying fungi, 177-180;
 structure of, 177

- Worms, 370, 376-385; intestinal, 383
Wounds, 278-283
Yeasts, 193-202; spores, 194; wild
and cultivated, 196
Yellow fever, 266, 414
Xylem, 126
Zone of growth, 82

100

